21

Simulating a Land Development Planning Process through Agent-Based Modeling

Michael Kieser[1,2] and Danielle J. Marceau[2]
[1]Tesera Systems Inc., Cochrane, Alberta,
[2]Department of Geomatics Engineering, University of Calgary, Calgary, Alberta
Canada

1. Introduction

Like most urban centers in North America, the City of Calgary has been experiencing steady population and unprecedented land-cover growth over the past six decades due to the strong Alberta economy, natural increase, and net migration (City of Calgary 2009). Between 1951 and 1961 the population exploded by 93% from 129,060 to 249,641 inhabitants and the city's jurisdiction swelled by 276% from 104 to 392 km^2. In each decade since, the population has increased by approximately 35% to the current population of 1,043,000 inhabitants and the city's municipal lands have expanded by 14% to the current area of 745 km^2 (Applied History Research Group 1997-2001; City of Calgary 2008). The City of Calgary's "Population Picture" predicts a population of 1.6 million by 2037 and just fewer than two million inhabitants by the 22nd century (City of Calgary 2009). If these population predictions are correct and planning and land development decisions continue to be made based on current planning policy and developers' self-interest, the City of Calgary will continue to sprawl and housing costs will continue to climb.

This competition and cost increase for land within the City of Calgary force young families unable to afford a house in the city to purchase outside of the city and commute to their place of employment. It also encourages retirees wanting to get away from the city to move out to the country. This creates demands on towns located in the vicinity of Calgary to accommodate this net migration. This is the case for the Town of Strathmore, located at about 40 km east of Calgary on the Trans-Canada Highway. It currently has a population of 11,335 inhabitants and covers approximately 15.5 km^2. The population is expected to reach 56,731 inhabitants by 2056 and to cover 26.8 km^2, an increase of 38% in population and 12% in area per decade (Brown and Associates Planning Group 2008).

Several environmental, social and economic problems are associated to population growth, including: (a) increased demand on and cost for resources such as land and water; (b) increased intensity of use on and competition for land; (c) change in settlement patterns; (d) increased interaction, and conflict or required cooperation with adjacent municipalities; (e) increased demand on existing infrastructure, such as roads, utility distribution, collection and treatment facilities; (f) increased cost for new infrastructure like roads, utilities, schools, and other community facilities; (g) increased environmental ground, water and air pollution; and (h) increased health and emergency costs. Some of these costs can be avoided;

some cannot, but most can be reduced. This brings several questions to mind: (1) who is making the planning policy decisions?, (2) what are the goals and objectives of the decision makers?, (3) how are the decisions makers interacting when making their decisions?, (4) do the decision makers know the impact of their decisions?, and (5) do the decision makers have the tools to: (a) predict the future impact of their decisions should they continue making similar decisions, and (b) predict the future impact of their decisions if they were to change their goals?

The development of a parcel of land for residential purposes requires the planning of the physical and legal changes to the land. The physical changes include designing the size and configuration of the proposed site infrastructure such as site grading, road design, storm water control system, and the servicing of water, sanitary sewer, electrical, communication and gas utilities. In Alberta, the documents regulating the legal changes include subdivision and land-use redesignation. Land-use is regulated through the following documents in hierarchical order: the Alberta Municipal Government Act (MGA), the Inter-Municipal Plan (IMP), the Municipal Development Plan (MDP), planning documents of the municipality, Land-use Bylaw, and Land-use (LU) Redesignation (Fig. 1).

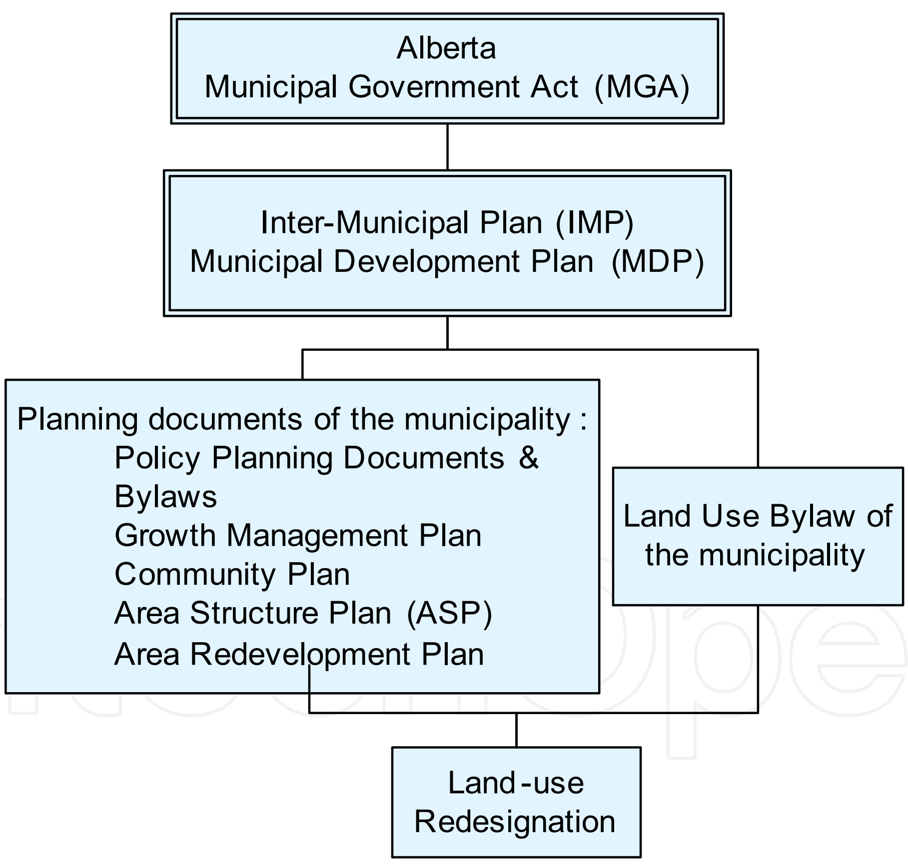

Fig. 1. Hierarchy of planning documents regulating land use in Alberta

The following is a summary of the Land-use Redesignation and concurrent Outline Plan process, from here on referred to as the *land development planning process,* in the City of Calgary assuming a MDP and an ASP are in place (City of Calgary 2008). This process is similar in the Town of Strathmore. However, the administration is smaller and is not divided into as many individual departments resulting in fewer decision makers making more decisions. First, the landowner and/ or developer attend a pre-application meeting with the city planning authority to discuss the proposed redesignation. Then, the landowner/ developer voluntarily presents the plan to the neighbours and local community association. The landowner/ developer submits the application for land-use redesignation and outline plan that he has worked on with professional planning and engineering consultants and sub-consultants, to the planning authority. Then, the application is circulated to the various City departments, the community association, the Alderman, and any applicable special interest groups and a notice is posted. The various planning authorities review the application and the comments and make a recommendation to City Council. Notices are sent to adjacent owners, a sign is posted, and an advertisement is placed in the local newspapers regarding a public hearing on the application. Finally, the proposed land-use redesignation and outline plan application are presented in a public hearing and the City Council makes its decision.

As one can see, this process involves many stakeholders including: the landowners, the developers and their engineering and planning consultants, the city/ town authorities and their various departments, the neighbours and other citizens, the community associations, the city/ town political figures, the utility providers, and other special interest groups. One can imagine each stakeholder or group of stakeholders having different visions, opinions and interest in the proposed development. The authorities must also have in mind the broader picture and overall goals of the city/ town itself, and attempt to see how the proposed land development fits into the future plans of the community. Throughout the process, communication occurs between different stakeholders on many occasions, both within an organization and with other organizations. Communication also occurs at many formal and informal levels, including: pre-application meetings with city/ town authorities, meetings with neighbours and community associations, meetings with private planning and engineering firms, open houses, application reviews by authorities and the public, decisions by city/ town authorities, public hearings, and possible appeals. Prior to these communication sessions, stakeholders are trying to devise ways to fit their goals into the proposed development. During the sessions, negotiations take place to balance goals and resolve issues and hopefully make decisions. As stakeholders make decisions, they might weigh social need, environmental impact, economic advantages or disadvantages and political support or opposition of a proposed land development.

Municipal and inter-municipal planners use various methods and tools to create a municipal plan that best suits the ideals, values and vision of the community in terms of future social need, economic feasibility, and environmental sustainability. These methods include forecasting based on present conditions using historical data, past success and failures. Some of the tools include statistical census analyses, and community economic models to predict employment creation. The growth plans and planning policy developed for a municipality set the direction of the community growth, which may leave limited choice for developers and citizens. One of the outcomes, which is the focus of this research, is a decision that changes land use allowing for development to occur on a particular parcel of land. Despite the array of methods and tools available, these decisions are still often made in the face of uncertainty. The central issue addressed here is that town planners have a limited, although improving, ability to forecast the cumulative effect of individual decisions made by stakeholders having different goals on the overall environment over which they make their decisions. They need a tool that can model how environmental patterns and trends emerge from the intricate interactions and complex behaviour of several stakeholder groups who might have conflicting goals and views. Having access to such a tool would enable environmental impact forecasting of current goals, decisions and policies, and would allow stakeholders to perhaps modify their goals and analyze possible future impact before the implementation of their decision. Increasingly, computer simulation models, such as agent-based models (ABMs) are being used to support decision making in complex environmental management situations (Marceau 2008). The *land development planning process* is the type of complex systems where ABM can provide this support.

ABMs are an abstraction of real-world entities called agents having typically the following properties: they are autonomous, they control their own decisions and actions; they are social and can negotiate and cooperate with one another; they are able to perceive changes in the environment and react to them; they have goals and are able to take initiative to achieve them (Wooldridge 2000). ABMs are typically discrete, disaggregate, dynamic and spatially explicit, meaning that they simulate the processes that occur over time between individual agents that interact and act upon a simulated geographic region. Over the past fifteen years, ABMs have contributed to modeling in the natural and social sciences in the areas of human/ wildlife interaction (Bousquet et al. 2001; Anwar et al. 2007; Beardsley et al. 2009; Bowman and Thompson 2009; Musiani et al. 2010), human/ landscape interaction (Gimblett et al. 2001; Gimblett et al. 2002), urban pedestrian movement (Batty 2001; Waddell 2002), water/ forest/ agriculture resource management (Janssen et al. 2000; Feuillette et al. 2003), spatial planning (Ligtenberg et al. 2001), and land-use and land-cover change (Lim et al. 2002; Parker et al. 2002; Monticino et al. 2007; Moreno et al. 2007; White et al. 2009). When used for spatial planning, ABMs are often linked to a cellular automata model (Parker et al. (2002). In such a case, the ABM component represents humans making decision and interacting over their environment as agents. The cellular automata component is a cell-based map that simulates the environment that agents view and act upon.

The objective of this research is to develop an ABM to simulate the land development planning process in a particular case study, which is a proposed residential subdivision in the Town of Strathmore called Strathbury. The land development planning process includes the Land-use Redesignation and Outline Plan process as shown in Fig. 1. The model will then be used to investigate the impact of changes to governmental regulations, planning policies, design standards and stakeholder goals on land-use resources. For the purpose of this research, land-use resources are defined as parcels of land having a potential for development that currently do not have the land-use designation to allow for development but that could be redesignated.

2. Methodology

The following eight steps in creating the ABM (Kimmins et al. 2004, Wainwright et al. (2004) have been applied in this research: (1) identification of the study area, (2) abstraction of the real-world system through a conceptual model, (3) collecting the information needed for the implementation of the model, (4) implementation of the model, (5) the computational logic of the model, (6) calibration and verification of the model, (7) scenarios simulation, and (8) validation of the model results. They are presented in details in the following sections.

2.1 The study area

The study area is a proposed residential land development project called Strathbury corresponding to 80 hectares of undeveloped piece of property located at about 0.5 km northwest of the downtown core of the Town of Strathmore; it is within the adopted Strathmore Lakes Estates Area Structure Plan (ASP). The simulation scenarios were tested over an area of approximately 3000 hectares that includes the Town of Strathmore and 1.6 km of the surrounding Wheatland County (Fig. 2).

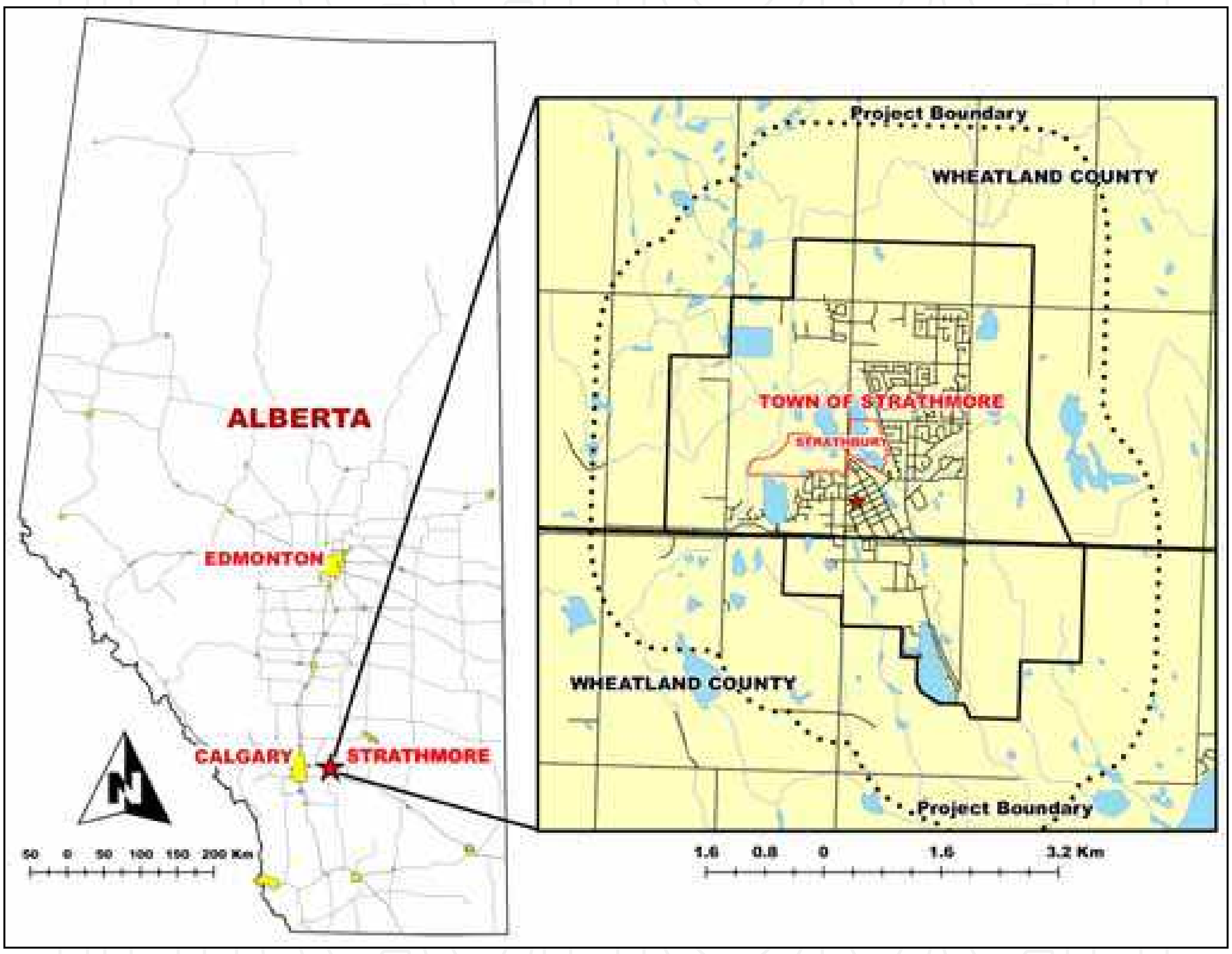

Fig. 2. Location of the study area; the dashed line represents the extent of the model simulation; the continuous line represents the Town of Strathmore boundary

2.2 Abstraction of the real-world process

The conceptual model, expressed as a UML diagram (Fig. 3), displays the two model components, the agent-based model and the raster-based land-use change model that were built to simulate the *land development planning process*. The agent-based model simulates the planning process including the goals, interactions, and decision making of stakeholders, taking into account economic factors, social factors, and regulations. The raster-based land-use change model simulates the environment that is deliberated, applies the land-use change from an approved development, and simulates into the future.

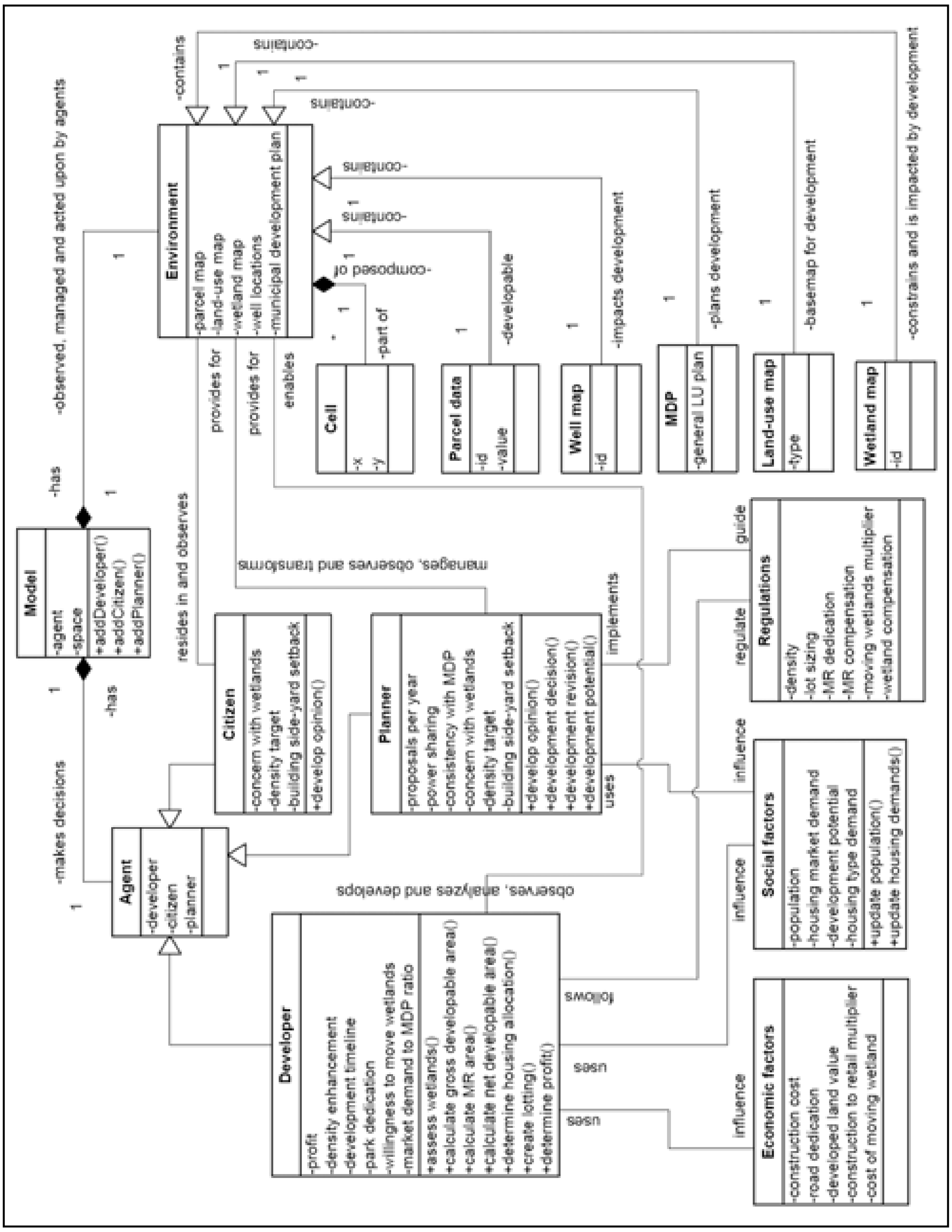

Fig. 3. The conceptual model

2.2.1 Agent-based component

The key stakeholders that were abstracted from the real-world *land development planning process* are the Developer, the Planner and the Citizens. The Developer combines those stakeholders that have financial interest in the development of the Strathbury project: the land developer who will profit from the conversion of the land into developable lots, and the engineering and planning firm who was providing consulting services to the land developer who will profit during the planning and preliminary engineering stages. The Planner combines those stakeholders that ensure the proposed land development follows governmental regulations with those in political positions that make decisions on the approval of proposed developments in the Town of Strathmore. They are the municipal planning department, the infrastructure department, the parks and recreation department, the emergency services department, and the Strathmore Town Council. The Town of Strathmore is a small municipality having only one Town Planner that advises the Town Council on a proposed development. The political arena, the Town Council, is not included in this model; therefore the assumption is made that the advice of the Town Planner on a proposed development is the decision of the Town Council. The Citizen includes those stakeholders that neighbour the proposed development, community associations, and other citizens in the Town of Strathmore. The citizens of the Town had particular environmental concerns regarding the Strathbury development and are therefore considered a key stakeholder.

Although electrical, gas, and communications utility providers do have financial interest in a proposed development, typically they are not involved in the decision making and are therefore not included in the model. Typically, if some utility infrastructure exists within the proposed development, such as high pressure gas, electrical transmission or communication towers, the proposed development may need to be planned around the existing facilities. If they can be relocated, the utility company may financially make the development more or less feasible by either absorbing the cost of utility relocation or passing the cost of relocation onto the developer.

2.2.2 Raster-based land-use change component

The key environmental state that was abstracted from the real-world *land development planning process* was the land-use designation on each land parcel. The environment was abstracted into raster-based cells of a uniform size with land-use values as attributes.

2.3 Information used in implementing the model

Five different types of information needed to represent the *land development planning process* were gathered and implemented in the model: 1) agent information, 2) social factors, 3) economic factors, 4) government regulations, and 5) spatial datasets.

2.3.1 Agent information: goals, decisions and factors influencing decisions

The first step in developing the agent-based model was to determine for each of the stakeholders, namely the Developer, the Planner and the Citizen, the specific goals they are attempting to fulfill, how they make decisions, the factors that influence their decisions, and how they communicate with each other. The document entitled "A Community Guide to the Planning Process" outlines the general Land-use Redesignation and Outline Plan process that is applied in southern Alberta and by the Town of Strathmore (City of Calgary (2002). This document guided the collection of information from the stakeholders.

For the Developer and the Planner stakeholders, information was gathered in three stages: through a questionnaire, a formal interview, and an unstructured interview. Individuals that were directly involved in the Strathbury *land development planning process* included the Planner for the Town of Strathmore, and the Strathbury land developer from WestCreek Developments. A Professional Civil Engineer from Eclipse Geomatics and Engineering, who was contracted by the developer to do the engineering for the proposed development and who is considered an expert in the field of land development, was also contacted to provide information on the status of the Strathbury application, public hearing and council decision process, as well as insight on the *land development planning process* in the Town of Strathmore, the governmental regulations affecting land development, and the land-use change allocation.

A questionnaire was prepared based on preliminary discussions with the Town Planner and the Professional Engineer. It was provided to each representative stakeholder to answer. The information collected from the questionnaire was used to guide the structured interview. During the structured interview process, it was discovered that although the questions provided a general understanding of the factors influencing the decision process of the stakeholders, the depth was insufficient. An unstructured interview ensued allowing the representatives to talk freely about the planning process, their goals, how the decision process occurs, the information they use to make their decisions and how the *land development planning process* was going with the Strathbury project.

For the Citizen stakeholder, it was concluded that questioning only one citizen would be biased and questioning many citizens was unwarranted. During the unstructured interview, the Planner provided information on feedback he received through written and verbal communication with concerned citizens. In the public consultation for the Outline Plan and Land-use Redesignation associated to the Strathbury development, some motivated citizens provided written comments on the proposed development. These comments became part of the public documentation for the development and are summarized and addressed by the developer. Although this information may not represent the opinion of all citizens, it was the best available to represent the perspective of the Citizen stakeholder and was used in the model.

2.3.1.1 Developer stakeholder: goals, decision and influence

During the interview, the developer explained the general objectives that his company attempts to meet with all proposed land developments, including: profit, density, construction cost and timeline, and lot retail value. The developer discussed the general infrastructure issues that the Town of Strathmore needs to address prior to approving any development projects including: sweet gas well buffers, water sourcing and water treatment, sanitary sewer disposal, and storm water management. He also discussed specific details that pertain to the Strathbury development of which wetlands were the most controversial (Developer 2007).

The land developer wishes to maximize the number of market demanded lots by minimizing the lot size and increasing the density, to minimize costs - hence maximize profit, to provide building lots quickly, to provide the required Municipal Reserve (park space) rather than monetary compensation to the Town, to move wetlands when they interfere with the proposed design, and to follow the market demand for housing rather than the Municipal Development Plan. From this information, six properties were abstracted to become the Developer stakeholder goals: 1) profit, 2) increase residential density, 3) development timeline, 4) park dedication, 5) willingness to move wetlands, and 6) market demand to MDP ratio.

Many regulatory factors dictate the decisions of the land developer when planning a development including: the municipal development plan, the current and adjacent land use, the municipal land-use bylaw, the environmental regulations, and the law. Economic factors also influence the decisions of the land developer such as the housing market demand, the market value of developable lots, the construction cost, the cost of developable land, the distance to existing infrastructure, and the presence of wetlands within the land parcel. When making the decisions on a proposed development, the developer looks at different development schemes, applies the regulations, assesses all the influencing factors, and then "calculates" the most suitable and profitable scheme. If the developer performs his/ her "due-diligence", the proposed development plan on a parcel of land should be accepted (Developer 2007).

2.3.1.2 Citizen stakeholder: goals, decision and influence

Citizens are the source of values that define the community. They identify problems and provide feedback on solutions that are implemented. Typically the more involved citizens are in the community, the more influence they have on decisions affecting their community.
The comments provided by the citizens proved to be very useful in developing their general concerns regarding the Town's growth, the typical 'not in my back yard' (NIMBY) apprehension, the need for a park system, and the preservation of wetlands. The following quotations come from six different letters received by the Planner regarding the Strathbury project and are reflective of the comments given by the Planner during the interviews (Citizens 2006): (a) "strongly oppose the proposed amendments for the redesignation of the land directly behind our home; (b) the town "promotes green areas and Urban Reserves yet is proposing to build homes and condos on one of the most beautiful green areas remaining" in the town; (c) "the land has numerous ponds and we're very concerned about the water level specifically where the water will flow if homes are built in the area"; (d) "preserve (the Strathbury land) and further enhance it so that future generations of our residents and our wildlife will have the space to access"; (e) "we are desperately in need of areas to walk with our families"; (f) "we (want to) look well into the future and plan not only residential, business and shopping spaces, but areas (that) will enhance (the) quality of life"; and (g) "(the Strathbury land) is really an extension of the wetland across the road, and has several smaller wetland areas within it. Please preserve it with a plan for enhancement in the future".
The compiled information revealed these general desires of the citizens: they like the small town feel and they want to maintain it, they do not want the urban sprawl of Calgary, they like the network of walking trails within the town, and they feel the wetlands in their community are a great asset and want to maintain them as part of their park system. The Town planner verbally communicated a concern with the fire hazard associated with houses being excessively close. From this information, four properties were extracted to represent the Citizen goals in the model: 1) concern with wetland disturbance, 2) maintain Municipal Reserve (park space), 3) maintain density per the MDP, and 4) increase building side-yard setback.
In general the citizens' are greatly concerned by the impact on wetlands and the continuity of their park network. They evaluate the development proposal created by the developer mostly in terms of the impact on wetlands and the integration of park space and share their positive or negative opinion with the town planner.

2.3.1.3 Planner stakeholder: goals, decision and influence

During the interview, the Town planner described the Town's current zoning bylaws, the infrastructure issues, the trail network system, the municipal development plan, the density objectives, the future growth plans, and the wetland policy, which was recently updated following a public survey of the town's residents. He/ she also talked about his/ her role as a sounding board to residents' concerns and as an advisor to the Town Council. Details pertaining to the Strathbury development project itself were also discussed, including a goal of slightly increasing the density on account of its vicinity to the town centre, and the issue of wetlands (Planner 2007). Some frustration was expressed in having inherited an aged Municipal Development Plan and having to work with existing Planning Policies that really didn't match the sustainability, density and growth goals that were now desired. For over a year, the town planner had worked with the Town council on a new Municipal Development Plan (MDP) and almost had it adopted by the Council. At the time of the interview, the Town had just had a Municipal election that completely changed the Council members. As a consequence, the Planner would have to go through the entire process again before adopting the new MDP.

The town planner must interpret planning regulations for other municipal decision makers and be able to educate citizens about the benefit of community planning. He is the moderator between the land developer and the citizens over the wetland issues while meeting the needs of the growing community. He is also the citizen educator providing an open door for citizens wishing to discuss community planning and future plans of the Town. Opinions of citizens showing an interest and a genuine concern for the direction of the community planning within the Town of Strathmore are given more credence by the Planner. The information compiled from the interview revealed specific desires that the planner wishes to achieve for the Town: to implement a new community growth strategy (MDP) with a transit-oriented design, allowing for an increase in density in redevelopment areas near the town centre, to provide direction for the new developments within the recently annexed Town boundaries, and to solve storm and sewer infrastructure problems. From this information, seven properties were extracted to represent the planner goals in the model: 1) development approvals per year, 2) weight of citizens' opinion, 3) consistency with the town's municipal development plan, 4) concern with wetland disturbance, and the increase/ maintain/ decrease of 5) Municipal Reserve (park space), 6) density, and 7) building side-yard setback.

The regulatory factors that dictate the decisions of the planner when planning a development includes the municipal development plan, the current and adjacent land use, the municipal land-use bylaw, the environmental regulations, and the law. As the planning division in a city/ town is the authority on the municipal land-use bylaws and the Municipal Development Plan, the planner has the ability to interpret them differently. This flexibility has been captured in the "consistency with the town's municipal development plan" property of the planner. In addition, social factors influence the decisions of the planner including: the citizen involvement, the housing demand, the urban development potential, and the population growth. A key decision that must be made by the planner is related to the sharing of decision-making power with the citizens: the greater the involvement of the citizens, the more decision-making power they are given. The planner must evaluate the development proposal created by the developer in relation to the town's goals and the existing regulations. Then, a decision is made to accommodate the opinion of the citizens,

the housing demand and the town's municipal development plan, and the right of land owner, represented by the land developer, to develop his/ her property.
The planner is also responsible for updating the MDP every five to ten years, a process that involves public hearings, public consultation, and growth prediction. Since the new MDP had not yet been approved by Town council, it was not public documentation and therefore could not be supplied; however the planner provided some information on its general direction (Planner 2007).

2.3.2 Social factors influencing stakeholders' decision

Population growth and housing demand are influential in the decision making of the Planner, Developer and Citizen, making it necessary to balance the appropriate type and quantity of housing. The following is a list of the social factors impacting decisions abstracted for the model and how they were quantified as parameters in the model. The first factor is the population growth. The population of the Town of Strathmore in 2007 was 10728 persons (Planner 2007); the estimated population growth was calculated on a yearly basis from a population projection report (CH2M HILL 2007). The second factor is the housing market demand. The initial approximate value for the Town is 50 units (130 persons) in 2007 (Planner 2007). The future demand was calculated in the model on a yearly basis as the population growth, less the number of new homes created that year, multiplied by the average household size (2.6 persons/ household) (Statistics Canada 2007). The third factor is the development potential. It is a value estimated by the Planner that is based on the residential construction in approved residential land developments in the Town. Based on the approved developments, an estimated 125 units (325 persons) could be built in 2007/ 2008 (Planner 2007). The fourth factor is the housing type market demand: initial values (50% R1 (residential one), 15% R2 (residential two) with a 25' wide lot, 10% R2 with a 30' wide lot, 15% R2Xatt (residential two-X attached), and 10% R2Xdup (residential two-X duplex) for each housing type for the Strathbury development were provided by the Developer during the interview (Developer 2007). Since the market study only covered the Strathbury development, these numbers are assumed constant.

2.3.3 Economic factors influencing stakeholders' decision

The land cost, construction costs, and market value for developable lots are influential in the decisions made by the Developer. The following is a list of the abstracted economic factors and how they were quantified as parameters in the model. The first economic factor is the land value. Assessed land values ($/ hectare) were obtained for each developable cadastral parcel from the Assessment Offices of Wheatland County (2007) and the Town of Strathmore (2008). Knowing that the market land value for the Strathbury development land is approximately 2.5 times the assessed value, an assumption was made that all market values were 2.5 times the assessed land value. The second factor is the construction cost per metre of lot frontage. From experience, the developer has determined an approximate cost per linear metre of lot frontage that includes all the construction costs of $3000/ foot of lot frontage ($10000/ m of lot frontage) (Developer 2007). The third factor is the percentage of road dedication. From experience, the developer has determined an average percentage of the developable area that is dedicated to roads of 29%, of which 34% are 22 m wide collector streets and 66% are 15 m wide local streets (Developer 2007). The fourth factor is the developed land value. From experience, the developer knows the approximate retail value for the different housing types (residential-1 lot (R1): ~$450000, residential-2 25' wide lot (R2-25): ~$250000, residential-2 30' wide lot (R2-30): ~$300000, residential-2X duplex lot (R2Xdup): ~$225000, residential-2X attached lot (R2Xatt): ~$200000) (Developer 2007). The fifth factor is the construction to retail value multiplier. From experience, the developer has devised a multiplier to use when determining the development feasibility and profit. The minimum retail value should be three times the construction cost. If the construction costs are lower or the retail value is higher than a profit is made. Conversely, if the construction costs are higher or the retail value is lower than a loss is declared (Developer 2007). The last factor considered is the cost of moving wetlands. According to the Alberta Government (2000), the cost of constructing wetlands varies between $12,000 and $60,000 per hectare. Included in these costs are the land, design, earth moving, planting, monitoring and maintenance.

2.3.4 Governmental regulations

Municipal governmental regulations, implemented by the Planner, must be followed by the Developer when proposing a development. The following is of list of the abstracted land-use regulations and how they were quantified as parameters in the model. The first regulation concerns density. The average density as outlined in the Land-use Bylaw and MDP is 15 units/ hectare (6 units/ acre) (Town of Strathmore 1998). The second regulation is the lot sizing. The minimum lot width and lot area values were obtained from the Strathmore Land-use Bylaw (Town of Strathmore 1989). The third and fourth regulations are the minimum lot area: R1=464 m^2, R2-25=255 m^2, R2-30=302 m^2, R2Xdup = 232 m^2, R2Xatt = 185 m^2, and the minimum lot width: R1=15 m, R2-25=7.6 m, R2-30=9 m, R2Xdup = 7.5 m, R2Xatt = 6 m (Town of Strathmore 1989; Town of Strathmore 1998). Finally, the percent MR dedication or MR compensation was considered. The Alberta Municipal Government Act requires that proposed subdivisions provide part of the land as municipal reserve (MR) not to exceed 10% or monetary compensation (Government of Alberta 2000).

Two environmental regulations were abstracted and quantified as parameters in the model. The first one is moving wetland multiplier. In some situations, developers may consolidate existing wetlands within a proposed development. Relocating wetlands can be damaging and they are typically less productive. Wetland of 100 to 300% of the original wetland size may be required. The second environmental regulations concern the wetland compensation. In situations where wetlands are destroyed, a monetary compensation of ~$18,000/ hectare must be paid to an environmental protection organization.

2.3.5 Spatial datasets

A GIS (Geographic information system) database was developed using the ArcGIS software from Environmental Systems Research Institute (ESRI) to integrate the relevant information about the study area. Among the spatial datasets used in the model are the cadastral parcels: AltaLIS (2007) cadastral parcel data were obtained from the University of Calgary Maps, Academic Data, Geographic Information Centre (MADGIC) in vector format. The assumption was made that large undeveloped or Greenfield land parcels, closer to existing infrastructure, and closer to the center of the Town of Strathmore will be developed first. Therefore, urban reserve (UR) and agricultural (AG) parcels were weighted according to their size, distance to existing roads, and distance to the downtown core of Strathmore. Parcels were sorted by their weight, highest to lowest, and given a unique parcel identifier (Parcel No. 1, 2, 3…); the Strathbury project was Parcel No. 2 in the sequencing.

A land-use map of the study area was produced. AltaLIS (2007) vector cadastral parcel data were attributed land-use values from the Town of Strathmore (2007): 1, 2, 3, 4 = various types of commercial, 5 = public service, 6, 7 = various types of industrial, 8, 9, 10, 11, 12, 13 = various types of residential, 14 = municipal reserve, 15 = environmental reserve, 16 = open space, 90 = agriculture, 91 = urban reserve, 92 = Western Irrigation District (WID) canal, 99 = road.

Another source of data is the Municipal Development Plan. The quantifying of the MDP required the rework of the land-use map in the existing MDP (Town of Strathmore 1998) based on the information provided by the planner during the interview. In general the MDP requires 45% residential one (R1), 25% residential two (R2) and 30% residential two-X (R2X). Each residential parcel was given land-use percentages based on the information provided and stored as: [Parcel No., 45, 25, 30]. The Strathmore Lakes Estates Area Structure Plan further regulates the percentages of the Strathbury lands to 30% R1, 45% R2 and 25% R2X; therefore its values are stored as: [2, 30, 45, 25].

Finally, the Strathmore Wetland Inventory map from the Town of Strathmore (2007) was digitized into vector format. Gas well locations were provided by the Alberta Energy Resources Conservation Board (ERCB) (2007) in vector format.

2.4 Implementation

This section presents how the five types of information described in the previous section were implemented within the model.

2.4.1 Agent implementation: properties and decision functions

The goals of each stakeholder type and the factors influencing their decision were abstracted to become the properties of the agents, and the decision making was abstracted into decision functions with property variables. The properties and results of decisions from each agent type were quantified as numerical values, stored as arrays of numbers, or tuples.

In the implementation, each agent type was given an *opinion* property that ranges from -1 to 1 (negative opinion to positive opinion) and a *happiness* property that ranges from 0 to 10 (unhappy to happy). At different steps throughout the model, an agent evaluates the results of a decision and develops an *opinion*. A comparison is done between values contained in the decision tuple and values contained in each of the agent's properties tuple. If the result of a decision is contrary to an agent particular property, it will have a negative (-1) impact on his opinion regarding that property; if the result of a decision is similar to an agent property it will have a positive (+1) impact regarding that property. The average opinion is calculated and is weighted by 10 less the happiness and is stored as the agent *opinion* property; therefore the *opinion* of an unhappy agent will be stronger. The *happiness* property of an agent fluctuates according to how his *opinion* is accepted. If his *opinion* is ignored in the following development decision, it will lower his *happiness* and if it is well received, it will increase his *happiness*. Fig. 4 provides an example of the calculation.

Provision was also made for weighing each agent property allowing for different properties to be given more or less importance when developing an *opinion*. This was implemented in a Multicriteria Decision Analysis fashion using an Analytic Hierarchy Process (AHP) method called the pairwise comparison (Malczewski 1999). Each pair of criteria, or properties, is evaluated separately; one property is given an intensity of importance value over another property. The values range from 1 to 9 (equal importance to extreme importance) and they are entered into a matrix form. The values in pairwise comparison matrix are then checked for consistency by normalizing the eigenvector by the eigenvalue of the reciprocal matrix. If the consistency ratio is less than a certain value, then the values are said to be consistent; if the consistency ratio is greater than the value, the importance values are not consistent and they must be re-evaluated. A weight for each property is also derived, the sum of which equals 1. The weights are then normalized with the smallest weight being equal to 1. The normalized weight is applied to each opinion (+1/0/-1) before the agent *opinion* is developed, as previously discussed.

AGENT HAPPINESS:
  Citizen: 8
  Developer: 7
  Planner: 8
AGENT PROPERTIES:
  Citizen: maintain density of 6.0 and do not disturb wetlands
  Developer: increase density and willing to move wetlands
  Planner: increase density and do not disturb wetlands
PROPOSED DEVELOPMENT:
  Developer: density of 6.5 and wetlands are disturbed
AGENT OPINIONS:
  Citizen: -1 on density, -1 on wetlands, average = -1, weighted = -2
  Developer: +1 on density, +1 on wetlands, average = +1, weighted = +3
  Planner: +1 on density, -1 on wetlands, average = 0, weighted = 0
DEVELOPMENT DECISION:
  Planner: approve
AGENT HAPPINESS:
  Citizen: 6
  Developer: 10
  Planner: 8

Fig. 4. Example of agent opinion and happiness calculation

The benefits of using this method over a straight rank weighting are twofold. First, the resultant weights are not only relative to one another, but they also have absolute values; second, the user only compares two goals at a time rather than subjectively weighting all goals at the same time (Malczewski 1999). The pairwise comparison method was used by Malczewski et al. (1997) in a multicriteria group decision-making model to analyze environmental conflict. In the model, stakeholders in planning or resource management positions evaluate the suitability of land for different socio-economic activities. The research of Malczewski et al. (1997) showed that the pairwise comparison method allowed the stakeholders to objectively derive weights for the various land uses, rather than subjectively assigning them.

2.4.1.1 Developer agent properties and decision functions

The properties of the Developer agent are stored in the *developer tuple* and were implemented as follows: (1) *Profit*: the goal on the return on the capital investment put into the land parcel: 5 to 20%; (2) *Density enhancement*: the goal to increase the allowable density: 0 to 2 units/acre; (3) Development timeline: the goal on the start and expected completion of construction. Also used to derive the *development potential* per year, (a) *Start construction*: 1 to 5 years, (b) *Finish construction*: 2 to 10 years; (4) *Park dedication*: The Developer's goal regarding the creation or monetary compensation of Municipal Reserve: create MR = 1, provide compensation = 2; (5) *Willingness to move wetlands*: The Developer's view on the displacement of wetlands to accommodate the proposed development: Move = 1, Don't move = 0, (5.1) *Size of wetland moved*: The maximum size of a wetland the Developer is willing to displace: 1000 m^2 to 40000 m^2; and (6) *Market demand to MDP ratio*: The Developer's stance when weighing the housing market demand versus the MDP: 0.1/ 1 to 4/ 1.

Typically an application for a development submitted to the town planner contains a report, several plans and other required independent studies. In the model, these documents have been abstracted as a sequence of numbers that translate the content of those documents submitted as a proposed development into a *development tuple*. The *development tuple* contains the results of the above Developer decision functions, which will be discussed next. The values contained in the *development tuple* include: the proposed cadastral unique parcel identifier, the proposed density, the timeline for the land development project, the percentage of each land-use type, the residential lot dimensions and number of lots of each residential type, and the wetlands proposed to be displaced.

The following is a description of how the eight decision functions of the Developer were implemented: (1) *Wetland assessment function*: The Developer calculates the size of wetlands impacting the development and determines if any wetlands are below their maximum *Size of wetland moved property (5.a.)*. If wetlands are to be moved, their total area is multiplied by the *Moving wetlands multiplier* and the area is added to the existing wetland area; (2) *Gross developable area function*: The Developer determines the amount of developable area, which is the gross area less the Environmental Reserve (ER) or wetlands from the *wetland map*; (3) *Municipal Reserve (MR) function*: The Developer determines the amount of land to be dedicated as MR (park) from the developable area based on the *Percent MR dedication* parameter; (4) *Net developable area function*: The Developer determines the area of developable area that will be residential and that will be road based on the *Percentage of road dedication* parameter; (5) *Housing allocation function*: The Developer uses the *Market demand to MDP ratio* property and weights the market demand for residential lot types: R1-detached, and R2(X)-semi-detached(attached), with the allocation in the *Municipal Development Plan (MDP)*; (6) *Lotting function*: The Developer determines the number of lots based on the *Minimum lot area* and *Minimum lot width* for each residential lot type, the *Density* regulation parameters, and its *Density enhancement* property; the lot depth is optimized to use all the developable area; (7) *Profit determination function*: The Developer determines the profit in the proposed development as the market value for sold lots, comparing the *Developed land value* to the construction cost, which is a function of the *land value*, *Construction cost per metre of frontage*, the amount of lot frontage, and the *Construction to retail value multiplier*; and (8) *Opinion function*: The Developer compares, as discussed in 2.4.1, the appropriate values in the *development tuple* with the first five values in the *developer tuple*. Although the Developer follows its properties when initially proposing a development, due to the social and economic influences and governmental regulations the resulting proposed development may not meet its goals, impacting the *Developer opinion*. The Planner may also ask to revise particular aspects of the development, discussed in section 2.4.1.3, that do not meet the goals of the Developer.

2.4.1.2 Citizen agent properties and decision functions

The properties of the Citizen agent are stored in the *citizen tuple* and were implemented as follows: (1) *Concern with wetland disturbance*: The Citizen's view on the displacement of wetlands to accommodate the proposed development: Concerned = 1, Not concerned = 0; (1.1) *Size of wetland moved*: The maximum size of a wetland the Citizen is willing to see moved: 1000 m^2 to 40000 m^2; (2) *Density target*: The Citizen's goal regarding the density in proposed developments: increase the density = +1, maintain the current level in the bylaws = 0, decrease the density = -1; and (3) *Building side-yard setback*: The Citizen's goal regarding the distance between residential buildings as a fire protection measure: increase the current building setback = +1, maintain the current building setback = 0, decrease the current building setback = -1. The *opinion function* of the Citizen was implemented through a comparison of the appropriate values in the *development tuple* with the values in the *citizen tuple*.

2.4.1.3 Planner agent properties and decision functions

The properties of the Planner agent are stored in the *planner tuple* and were implemented as follows: (1) *Consistency with MDP*: the Planner's goal on how consistent the proposed developments must be with the town's Municipal Development Plan: no varying from the MDP = 0%, to quite flexible = 20%; (2) *Concern with wetland disturbance*: the Planner's view on the displacement of wetlands to accommodate the proposed development: Concerned = 1, Not concerned = 0; (2.1) *Size of wetland moved*: The maximum size of a wetland the Planner is willing to see moved: 1000 m^2 to 40000 m^2; (3) *Density target*: the Planner's goal regarding the density in proposed developments: increase the density = +1, maintain the current level in the bylaws = 0, decrease the density = -1; (4) *Building side-yard setback*: the Planner's goal regarding the distance between the residential buildings as a fire protection measure: increase the current building setback = +1, maintain the current building setback = 0, decrease the current building setback = -1; (5) *Power sharing*: the Planner's view on the weight given to the opinion of the Citizen: 0.1 to 4; and (6) *Proposals per year*: the Planner's goal for the number of proposals to review per year: 1 to 10; this goal can also vary based on the housing demand.

The following is a description of how the decision functions of the Planner were implemented: (1) *Opinion function*: the Planner compares, as discussed in section 2.4.1, the appropriate values in the *development tuple* with the land-use allocation in *the Municipal Development Plan (MDP)*, the *housing demand* and the d*evelopment potential* of the town, the land-use bylaws (*density*, *minimum lot area*, and *minimum lot width*), and the first four values in the *planner tuple*; (2) *Decision function*: The Planner weights the *Citizen opinion* based on the *power sharing* property. The sum of the *opinions* of the agents is calculated. If the sum is positive the decision is an approval; if the sum is negative, the Planner requests revisions. A decision of rejection occurs after four revisions; (3) *Revision function*: A request for revisions includes simple recommendations to the Developer regarding the proposed development. These recommendations are based on the *opinions* of the Citizen and the Planner: "(Increase/ Decrease) density", "(Increase/ Decrease) lot width", "(Increase/ Decrease) development time", "(Increase/ Decrease) MR dedication", "Follow MDP more closely"; and (4) *Development potential function*: The Planner evaluates the *development potential* on a yearly basis based on the *development potential* of the previous year, less the *housing market demand* for that year, plus the *development potential* of approved residential land development projects whose construction timeline contributes to the *development potential* for that year. As an example, if in the current year a development containing 200 units is approved having a *start* and *finish construction* timeline of one and five years respectively, the development will contribute 50 units per year to the *development potential* for the following four years.

2.4.2 Social and economic factors and governmental regulations implementation

The social factors, the economic factors, and the governmental regulations were abstracted into model parameters. The following describes how each of the parameters is stored: (1) *Population growth*: variable calculated yearly; (2) *Housing market demand*: variable calculated yearly; (3) *Development potential*: variable calculated yearly; (4) *Housing type market demand*: stored as a constant for each residential housing type; (5) *Land value*: stored as a two dimensional array with the unique parcel identifier; (6) *Construction cost per metre of frontage*: stored as a constant; (7) *Percentage of road dedication*: stored as a constant; (8) *Developed land value*: stored as a constant for each residential housing type; (9) *Construction to retail value multiplier*: stored as a constant; (10) *Cost of moving wetlands*: stored as a constant; (11) *Density*: stored as a constant; (12) *Minimum lot area*: stored as a constant; (13) *Minimum lot width*: stored as a constant; (14) *Percent MR dedication* and *MR compensation*: stored as constants; (15) *Moving wetlands multiplier*: stored as a constant; and (16) *Wetland compensation*: stored as a constant.

2.4.3 Agent-agent interaction

Agent-agent communication mimics the steps 2, 4 and 9 of the *land development planning process* (Fig. 3): (1) Developer - Planner: a development proposed by the Developer as a *development tuple* is submitted to the Planner and is circulated to the Citizen; (2) Citizen - Planner: the Citizen shares its *opinion* regarding the proposed development with the Planner; and (3) Planner - Citizen and Planner – Developer: the decision of the Planner on a proposed development is shared with the Citizen and the Developer. A request for revisions includes the recommendations from the Planner *revision function*.

2.4.4 Agent-environment interaction

Agent-environment interaction occurs on several occasions within the model as environment observations and environment transformations: (1) Observation by the Developer: the Developer observes the wetlands within the land parcel of the proposed development and evaluates them through the Developers *wetland assessment function*; (2) Observation by the Citizen: the Citizen observes the wetlands within the proposed development and generates an *opinion* based on how they are impacted; (3) Observation by the Planner: the Planner observes the wetlands within the proposed development and generates an *opinion* based on how they are impacted; (4) Transformation by the Planner: a decision by the Planner to approve a proposed development generates an immediate transformation of the *land-use map*. The transformation does not physically change the environment but it allows the Developer to begin construction.

Greenfield land-use change principles for residential developments, typically followed by developers, were developed for the environmental transformation of the *land-use map* with the assistance of an urban planner and the Civil Engineer. These principles are based on the existing land use, urban reserve (UR) or agricultural (AG), and its change to residential (R1,

R2, R2X), municipal reserve (MR), environmental reserve (ER), or open space (OS) based on the land use of parcels adjacent to the proposed land development parcel, and desirability. The land-use transformation for the parcel of land is based on the percentage of each land-use type values contained in the *development tuple* of the approved development, as discussed in 2.4.1.1. Examples of these principles, hard coded as land-use change rules in the model, include: wetland areas are surrounded by a linear park (MR) buffer; low density residential (R1) housing is placed adjacent to the more desirable open space (OS) and park (MR) and are minimized adjacent to the less desirable main thorough fares, commercial, industrial, and higher density residential land-use areas; medium density residential (R2 & R2X) housing is placed adjacent to the less desirable main thorough fares, commercial, industrial, and higher density residential land-use areas; a sizeable area of MR is usually set aside either for recreational fields or a future public facility (school, church, or community center). The transformation of the *land-use map* then affects the future land use of adjacent proposed developments.
The following eight steps describe how the transformation of the *land-use map* occurs within the model using the values contained in the *development tuple*: (1) The wetlands proposed to be moved are amalgamated with the largest existing *wetland* within the proposed development parcel; (2) *Wetland map* areas within the proposed development become Environmental Reserve (ER) cells and are given a 4 m ER buffer of cells; (3) *Gas well locations* are given a 50 m buffer around well sites that must be maintained as Open Space (OS) cells which can be used for recreation purposes; (4) The remaining cells are divided based on the percentage of each land-use type values contained in the *development tuple*; (5) 8 m wide linear parks (MR cells) are generated adjacent to ER, and the WID (Western Irrigation District) canal cells; (6) Medium density residential (R2 cells) is placed adjacent to existing main thorough fares, commercial, industrial, and higher density residential; (7) Low density residential (R1 cells) is placed adjacent to parks and open space and if necessary higher density residential; and (8) The remaining land becomes a sizeable area of MR cells.

2.4.5 Environment implementation

The environment that agents view and act upon was implemented as a raster-based landscape with a 16 m^2 (4 m x 4 m) cell size. The 4 m x 4 m resolution was chosen to accommodate the narrowest strip of land use. The different spatial data types were converted into a series of coincident raster-based maps using the ESRI ArcToolbox Conversion Tools Polygon to Raster and Raster to ASCII. The *cadastral parcel* data were converted into raster format with cell values of the unique parcel identifier. The *land-use map* was converted into raster format with cell values of the land-use type. The *wetland map* was converted into raster format with cell values of the unique wetland identifier. The *gas well locations* were converted into raster format. The *Municipal Development Plan (MDP)* data were stored in a text document.

2.4.6 Spatial and temporal boundaries

The spatial extent of the environment over which the agents make decisions includes all of the newly annexed lands of the Town of Strathmore and 1.6 km of the surrounding Wheatland County. The Town's Municipal Development Plan attempts to plan for a 30 year future growth, but is typically revised every five to ten years depending on growth rate. The ten year temporal boundary chosen for this study lies within the future plans of the Town's Municipal Development Plan, but only slightly exceeds the MDP revision period so as to give a reasonable but not extreme possible prediction of land-use change. A one year incremental time step was also implemented to update the population growth, housing demand, and housing potential; however the number of developments approved within the one year increment can be varied by the planner agent.

2.5 The computer model

Many existing programming environments exist for simulating agent-based systems including Swarm (Minar et al. 1996; Swarm 2010), Repast (Crooks 2006; Repast 2010), Mason (Mason 2010), and NetLogo (NetLogo 2010). However, to meet the particular needs of this case study, Java was used to develop the model for its familiarity and its object-oriented features.

2.5.1 User interface

An interface was developed to allow a user to view and modify the initial default property values. The default values in the interface are those developed from the information collected for the Strathbury land development project. The model interface contains three panels: 1) initial conditions, 2) run-time variables, and 3) land-use map.

2.5.1.1 Initial conditions panel

The Initial Conditions panel allows the user to modify the Developer, Citizen and Planner properties, the social and economic factors, and the governmental regulations. The matrix at the bottom of the interface for each agent is the pairwise comparison matrix that allows for the weighting of each agent property, as discussed in 2.4.1.

The following explains the interface that allows the user to set the nine Developer properties (Fig. 5a): (1) Initial "Happiness" (1-10): to set the initial *happiness* property of the Developer at the start of the model simulation; (2) Yrs Start: to set the number of years to *start construction* property; (3) Yrs Finish: to set the number of years to *finish construction* property; (4) MR (1=make/ 2=$comp): to set the *park dedication* property; (5) Wetland moved (m^2): to set the s*ize of wetland moved* property; (6) Move wetland (1=y, 0=no): to set the *willingness to move wetlands* property; (7) Extra density <: to set the d*ensity enhancement* property; (8) Mkt:MDP ratio (X/ 1): to set the *market demand to MDP ratio* property; and (9) Profit %: to set the *profit* property.

The interface for the Citizen properties (Fig. 5b) is similar to the interface for the Developer. It includes two unique properties of the Citizen: (1) Density (+1/ 0/ -1): to set the density target property; and (2) Bldg Setback (+1/ 0/ -1): to set the building side-yard setback property. The interface for the Planner properties (Fig. 5c) includes three unique properties: (1) Weight citizen opinion(X/ 1): to set the *power sharing* property; (2) Proposals/ Year: to set the p*roposals per year* property; and (3) +/ -% MDP: to set the *consistency with MDP* property.

The interface also allows the modeller to set the three social factors (Fig. 6a), the 18 economic factors (Fig. 6b) and the 14 governmental regulations (Fig. 6c). The social factors represented are (1) Base housing demand: to set the initial *housing market demand*; (2) Base Development potential: to set the initial d*evelopment potential*; and (3) Persons/ household: to set the average household size.

The economic factors include: (1) Const.&Marketing cost ($/ m lot frontage): to set the *Construction cost per metre of frontage*; (2) Cost:Market ratio: to set the c*onstruction to retail*

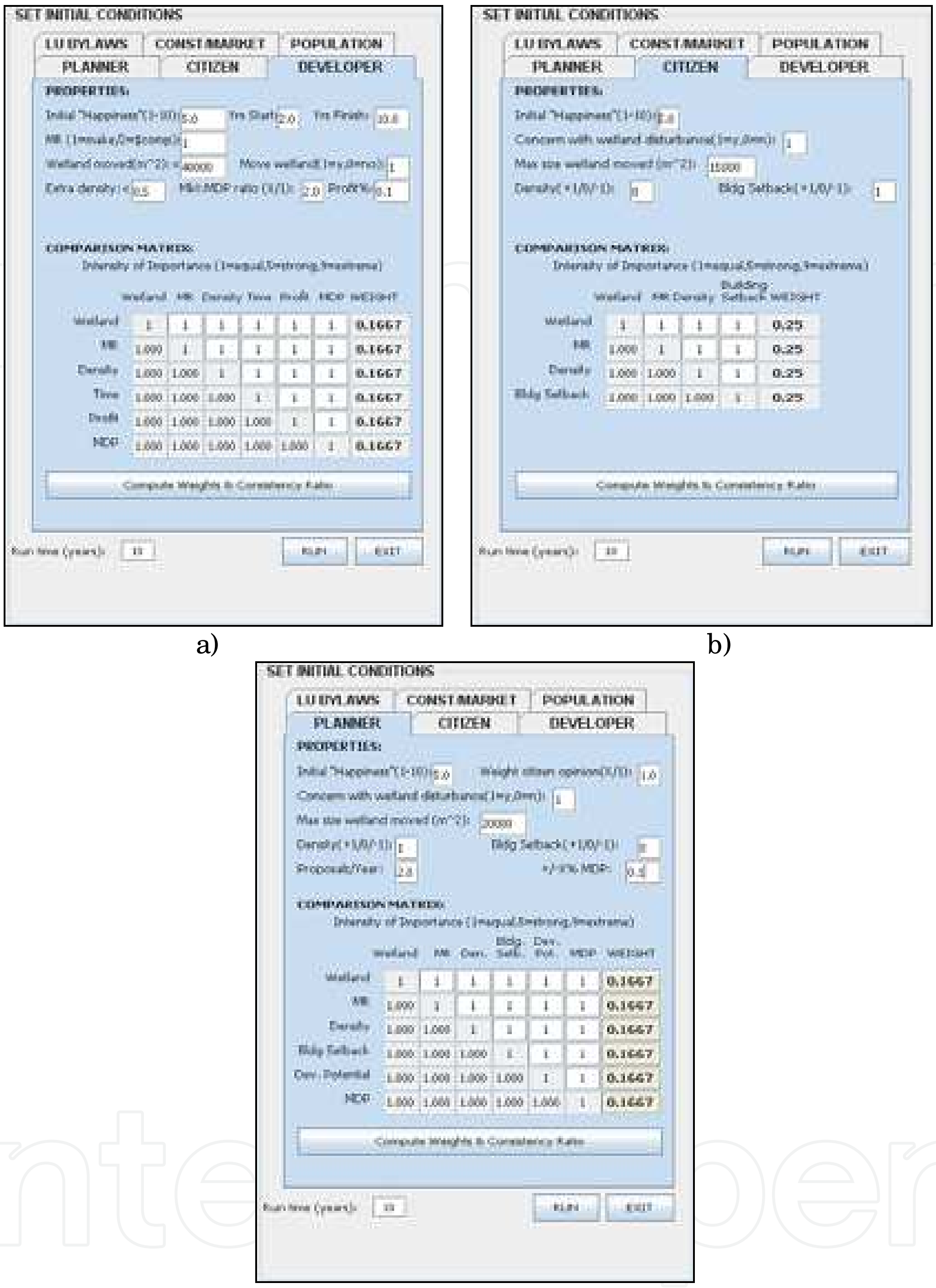

Fig. 5. Interface displaying a) the Developer, b) the Citizen and c) the Planner properties

value multiplier; (3) % Development road: to set the p*ercentage of road dedication*; (4 & 5) % Wide Road and Wide width: to set the percentage of collector roads and their width; (6 & 7) % Narrow Road and Narrow width: to set the percentage of residential roads and their width; (8-12) R1/ R2/ R2X market value: to set the *developed land value* for each housing type. The C1, P1, M1 & M2 market values were not used in the model; (13-17) R1/ R2/ R2X % of market: to set the h*ousing type market demand* for each housing type; and (18) Wetland moving cost ($/ hectare): to set the w*etland compensation*.

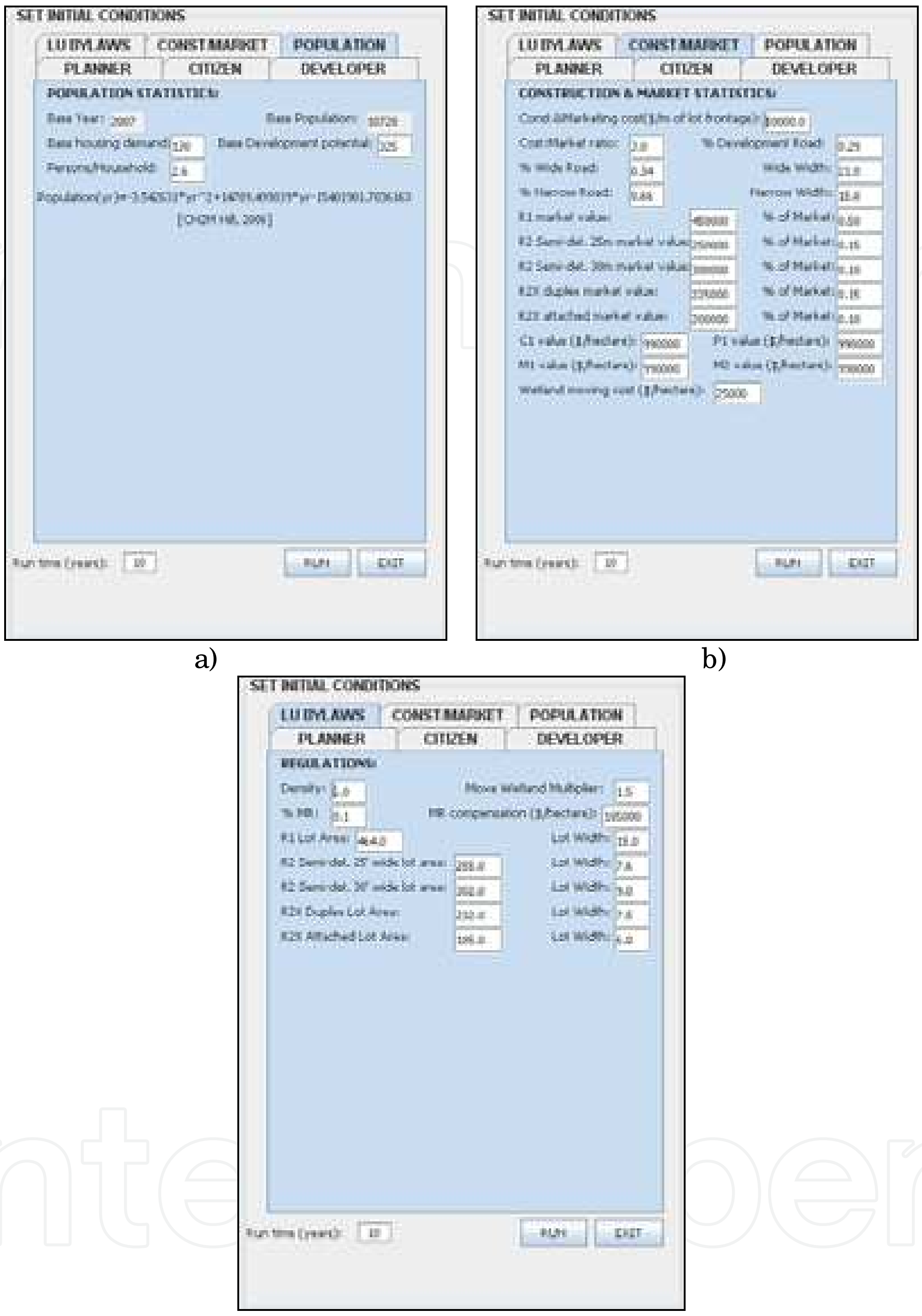

Fig. 6. Interface displaying a) the social factors, b) economic factors and c) the governmental regulations

The governmental regulations are (1) Density: to set the d*ensity* regulation; (2) Move wetland multiplier: to set the m*oving wetlands multiplier* regulation; (3) % MR: to set the *percent MR dedication* regulation; (4) MR compensation ($/hectare): to set the *MR compensation* regulation; (5-9) R1/R2/R2X lot area: to set the *minimum lot area* regulation for each housing type; and (10-14) R1/R2/R2X lot width: to set the *minimum lot width*.

2.5.1.2 Run-time variables panel

The run-time variables panel displays the decisions of agents, including the proposed development that has values contained in the *development tuple* discussed in section 2.5.1.1, the Citizens and Planners *opinions*, the *happiness* of each agent and the Planner's decision or recommendation (Fig. 7). The disabled check boxes in the run-time variables window are evidence of an attempt was made to implement agent behavioural change in the model and will be further discussed in the conclusion.

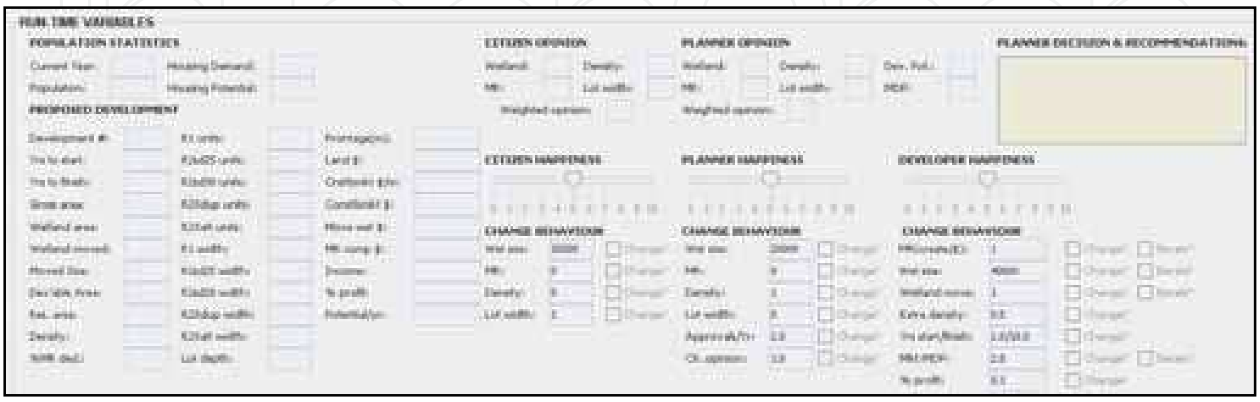

Fig. 7. Interface displaying the run-time panel

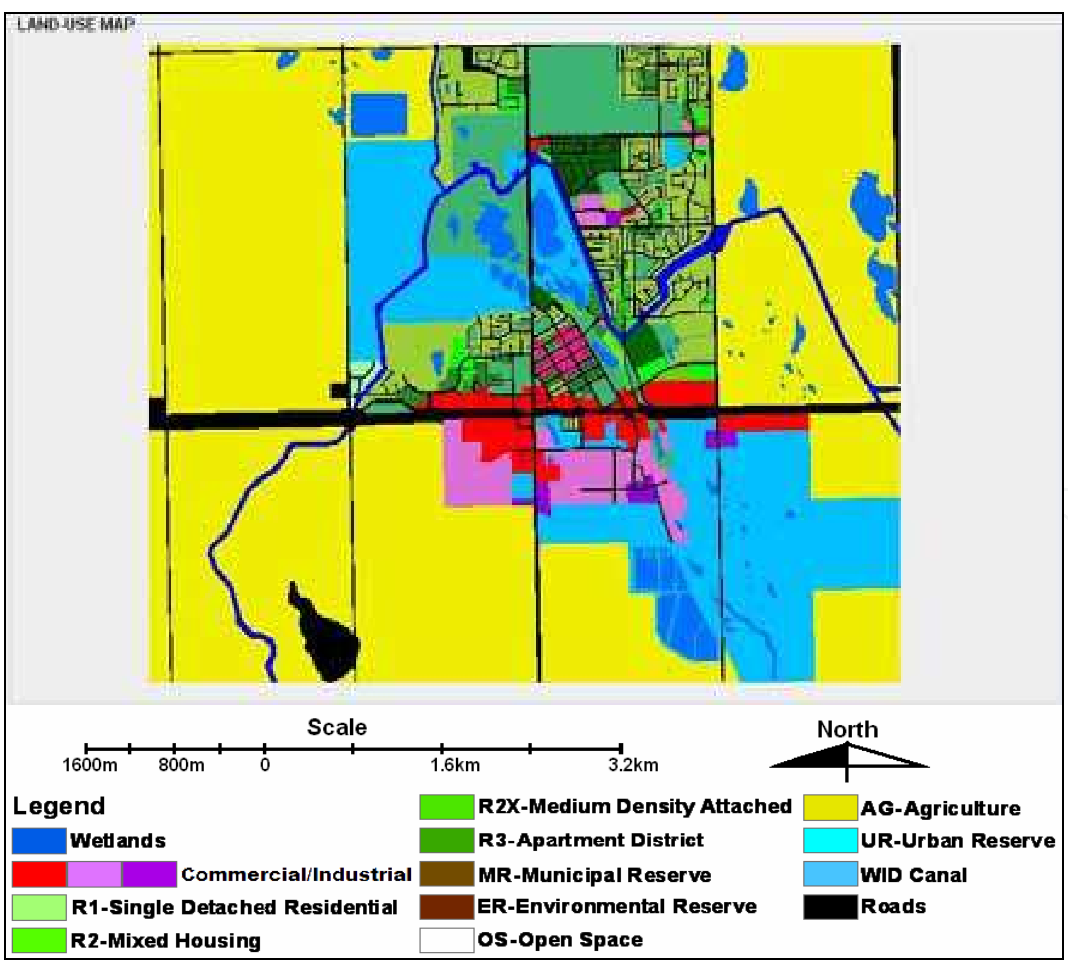

Fig. 8. Interface displaying the land-use map panel

In addition, the land-use map panel displays the changing land use as the development proposals are approved (Fig. 8).

2.5.2 The computational logic

The following ten computational steps were performed when simulating the *land development planning process* for a residential land development. 1) The software reads in the raster *land-use map*, the *wetland map*, and the *gas well locations*, the *cadastral parcel* sequencing, the *Municipal Development Plan (MDP)* information, and the *land value* data. 2) The parameters of the model initialization are populated with the default values, discussed in section 2.6, including: the agent properties, the social factors, the economic factors, and the governmental regulations. 3) The user is given the chance to change the model parameters. 4) The simulation year starts at 2007. 5) The next cadastral parcel in the sequencing, as discussed in 2.3.5, is observed by the Developer. The Developer performs the following functions: *wetland assessment*, *gross developable area*, *municipal reserve*, *net developable area*, *housing allocation*, *lotting*, and *profit determination*. A *development tuple* is produced and the Developer generates an *opinion*. 6) The Citizen performs its *opinion function* and shares its *opinion* with the Planner, as discussed in section 2.4.1.2. 7) The Planner performs its *opinion* and *decision function* and if required a *revision function*, as discussed in section 2.4.1.3. Based on the decision, the happiness of the Developer, Citizen and Planner are updated. 8) If the Planner decision is an approval, an environmental transformation to the *land-use map* occurs, as discussed in section 2.4.5. 9) If the Planner has not met the *proposals per year* approved property, steps 5 through 9 are repeated. 10) If the Planner has met the *proposals per year* approved property, the Planner's *development potential function* is performed. Finally, assuming that the maximum simulation time of 10 years has not been reached, the year is iterated and steps 5 through 10 are repeated.

2.6 Model calibration and verification

The model was calibrated using the agent goal parameter values, spatial datasets, social factor values, economic factor values, and governmental regulation values from the data that were collected from the stakeholders in the Strathbury land development project as model initialization parameter values. Verification of the computational logic of the model was done by walking through each calculation of the agent-based and raster-based land-use components and step by step comparing the calculated values to those calculated independently using a spreadsheet.

The *developer goal parameters* for the Strathbury development were initialized as follows: (1) has a construction timeline to begin construction in 2 years and finish in 10 years; (2) prefers to provide space for parks rather than having monetary compensation; (3) willing to move wetlands up to 4 hectares in size to suit the development; (4) tries to increase density by 0.5 units per acre; (5) housing market demand to Municipal Development Plan ratio is 2:1; and (6) wants a 10% rate of return on the investment in the project.

The *planner goal parameters* for the Strathbury development were initialized as follows: (1) gives equal weight to the opinion of the citizens regarding the proposed development during the decision-making process as a power sharing contribution; (2) is concerned with the movement of significant wetlands and would not like wetlands larger than 2 hectares to be displaced; (3) would like to increase the current residential density; (4) would like to maintain the current building setback per the zoning bylaws; (5) is quite concerned with the development potential; therefore it is given a greater weight; (6) in the past, has approved an average of two large development proposals per year which has kept up with housing demand; and (7) the consistency with the MDP is only +/ -5% since the MDP values have been revised to match the more recently adopted Strathmore Lakes Estates Area Structure Plan (ASP).

The *citizen goal parameters* for the Strathbury development were initialized as follows: (1) is concerned with the displacement of significant wetlands and would not like wetlands larger than 1.5 hectares to be moved; (2) would like to maintain the current density goal per acre per the zoning bylaws; and (3) would like to increase the current building setback per the zoning bylaws, because of a fire hazard concern.

The *social factors*, *economic factors*, and *governmental regulations* for the Strathbury development were initialized from the values discussed in section 2.3.

The agent-based component was calibrated by comparing the values of the results in the model run-time panel (Fig. 8) to the values in the development summary table of the Strathbury Outline Plan and Land-use Redesignation application. The raster-based land-use change component was calibrated by comparing the model land-use map results to the actual land-use maps generated for the Strathbury Outline Plan and Land-use Redesignation application. Comparisons were also made between the model run-time variables and two pre-application development Strathbury concepts, produced by the developer. The development concepts proposed slightly different densities, wetland displacement options and percentages of each housing type. The calibration results are presented in section 3.1.

Although the pairwise comparison matrix that enables weighting of agent properties was implemented in the model, as described in 2.4.1, in this application, all agent properties were given an equal weight.

2.7 Development scenarios

The following five scenarios were run with the model over a period of ten years, each having different initial conditions. The first scenario called “business as usual” (BAU) assumes that the regulations, goals of the stakeholders, and decisions made in the Strathbury project are typical and that decisions will continue to be made in this manner. The second scenario called “reduction in development approvals per year” only permits one development approval per year controlling the development potential and the rate of growth. The “increase in density” scenario modifies the Land-use Bylaws and Municipal Development Plan allowing the developer to propose a higher housing density. The “change in market housing demand” scenario accounts for a prediction by Ewing (2007) that the demand for residential housing types is going to change over with the retirement of baby boomers, through changing the Land-use Bylaws, Municipal Development Plan and the market demand for smaller housing types. Finally the “sustainable development” scenario controls the development rate, assumes an increased demand for smaller housing types, decreases the areas of road infrastructure scarring the environment, and does not allow the disturbance of wetlands.

2.8 Validation of the results

The results of the model were validated using a method called “face validation” (Ligtenberg et al. 2001). This method asks persons, such as professional planners, who are considered to be experts in the subject matter to compare the simulation results to their knowledge of the real-world system and make judgements on the results.

3. Result analysis

This chapter is divided into three sections. The first one discusses the results of the calibration and verification of the model as it simulates the proposed Strathbury development. The second section presents the result of each of the six development scenarios that were simulated. The third section addresses the validation of the model results.

3.1 Calibration results: the Strathbury development

As mentioned in section 2.6, the model results from the Strathbury proposed development values were compared to values contained in the development summary table within the actual Outline Plan and Land-use Redesignation application. Fig. 9 shows the model output values from the Strathbury proposed development.

PROPOSED DEVELOPMENT

Development #:	2.1	R1 units:	305	Frontage(m):	20722
Yrs to start:	2.0	R2sd25 units:	211	Land $:	7689489
Yrs to finish:	10.0	R2sd30 units:	202	Cnst&mkt $/m:	11000.00
Gross area:	797904	R2Xdup units:	161	Const&mkt $:	227946101
Wetland area:	164400	R2Xatt units:	76	Move wet $:	92080
Wetland moved:	36832	R1 width:	15.00	MR comp $:	0
Moved Size:	55248	R2sd25 width:	7.60	Income:	301589620
Dev'able Area:	593586	R2sd30 wdith:	9.00	% profit:	28
Res. area:	593586	R2Xdup width:	7.50		
Density:	6.500	R2Xatt width:	6.00		
%MR ded.:	0.100	Lot depth:	37.54		

Fig. 9. The model output values from the Strathbury proposed development

A comparison of the model results with the Outline Plan and Land-use Redesignation application development is shown in Table 1. The values of the model results versus the values contained in the Outline Plan and Land-use Redesignation application are within 0.1 to 3% of each other, a reasonable consistency for this research.

The undeveloped Strathbury parcel designated as urban reserve (UR) contains eleven wetlands (Fig. 10a). A road splits the east and west portions of the parcel. The west portion is bounded by the Western Irrigation District (WID) Canal on the west, public service to the north, and residential to the south. The east portion contains more wetlands; it is bounded by wetlands to the north, the WID Canal to the east and residential areas to the south. Fig. 10b shows the model results of the approved Strathbury land-use redesignation to residential, environmental reserve, and municipal reserve and the displacement and consolidation of eight wetlands. A detailed view of the actual land-use allocation map contained in the documents for the Strathbury Outline Plan application is displayed on Fig. 10c for comparison purposes. The percentage of each land-use type allocated by the model matches reasonably well the values contained in the actual Strathbury Land-use Redesignation and Outline Plan application.

Variable	Strathbury model results	Outline Plan application	Difference (%)
Gross Area (m^2)	797904	797229	0.1%
Environmental reserve (m^2)	201232	203557	1%
Developable area (m^2)	593586	593673	0.01%
Number of residential units	955	954	0.1%
Number of R1 units (units)	305 (32%)	315 (33%)	3%
Number of R2 units (units)	413 (43%)	410 (43%)	0.7%
Number of R2X units (units)	237 (25%)	229 (24%)	3%

Table 1. Comparison of the model results and the Outline Plan application development

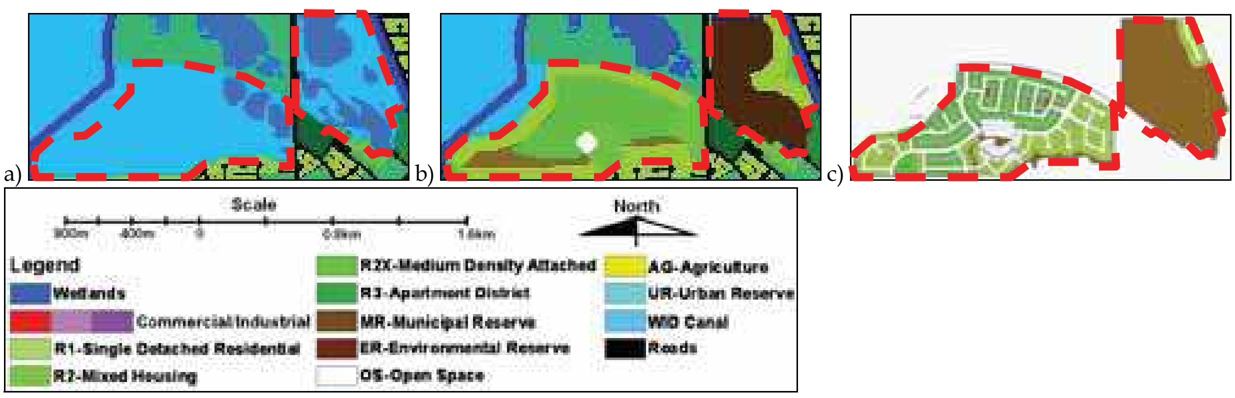

Fig. 10. a) The model land-use map prior to any development, b) the model land-use map of the Strathbury development, and c) the actual land-use map from the Strathbury Outline Plan and Land-use Redesignation application

Based on the initialization of the model with proper parameters values, the model produces results that are reasonably similar to the actual documents and plans of the Strathbury residential land development project. In general, the model adequately mimics the Strathbury Outline Plan and Land-use Redesignation application by the WestCreek developer, the opinion of the citizens, the decision by the Town to approve the Redesignation, and the land-use change.

3.2 Model run results

When analyzing the raster maps in the following scenarios, one must keep in mind that, contrary to reality in a land development process, the model does not include a detailed engineering infrastructure including water, gas and electrical supply and distribution, storm water collection and overland drainage, storm and sewer discharge, and road network.

3.2.1 Business as usual scenario (BAU)

The "business as usual" (BAU) scenario is based on an initialization from the Strathbury development goals and regulations and projecting into the future. Due to the age of the MDP the Developer is given additional leniency on the *Consistency with MDP* to 10%. Initially the Planner has a *happiness* of 9.0 to 10.0, continuously approving redesignation applications, trying to keep up with the *housing demand* and increasing the *development potential*. On three occasions the Citizen gives the proposed developments a negative *opinion* due to wetlands being displaced, but in general has a *happiness* of 4.0 to 6.0. During the years of approvals, the Developer has a *happiness* of 8.0 to 9.0 making profit. During year 6, the Planner requests a "decrease in development time", speeding up the potential for new housing, increasing the Developer *happiness* to 10.0. By year 9 the *development potential* has surpassed the *housing demand* and in the subsequent years the Planner requests revisions to "increase the development time", slowing the potential for new housing, decreasing the Developers *happiness* to 4. By the end of the simulation time, the *development potential* is 170% that of the *housing demand*.

Fig. 11a shows the land-use change over the ten year simulation period based on the BAU goals, regulations, standards and market parameter initialization. During the ten years of simulation, land-use change occurs over approximately 280 hectares contained within 17 land parcels. The percentage allocation of each residential land-use type follows the MDP regulations and *Housing type market demand*, and *Market demand to MDP ratio* of the Developer as expected: 47% R1, 23% R2 and 30% R2X.

3.2.2 Reduction in development approvals per year scenario

This model simulation starts with the Planner *proposals per year* reduced to one. During the simulation, the Planner and Developer maintain a *happiness* of 9.0 to 10.0, the Planner again continuously approving redesignation for proposed developments, trying to keep up with the *housing demand* and increasing the *development potential*, and the Developer content having all proposed redesignation applications approved. The Citizen has a slightly higher *happiness*, of 5.0 to 6.0, than in the BAU scenario, having fewer wetlands impacted. Over a ten year period, this scenario resulted in the *development potential* being 17% less than the *housing demand*.

Fig. 11b shows the land-use change over the ten year period based reduction in development approvals per year. Compared to the BAU scenario, the impact on land use occurs over a much smaller area, approximately 174 hectares contained within 10 land parcels; however, as expected, the land-use allocation and patterns are the same.

3.2.3 Increase in density scenario

This model simulation is initialized with a bylaw regulation *density* of seven units per acre. The Planner maintains a *happiness* of 9.0 to 10.0 throughout the simulation; the Developer's *happiness* is 9.0 to 10.0 for the first five years until the *housing demand* is met, when redesignation applications are no longer approved. The Citizen's *happiness* is 2.0 to 3.0 throughout the simulation due to the increase in density. This scenario results in the *development potential* being 70% more than the *housing demand* providing for a potential flood in the housing supply.

Fig. 11c shows the land-use change over the ten year period based on the business as usual parameter initialization, except for the increase in land-use bylaw density. Again, compared to the BAU scenario, the impact on land use is significantly less, being approximately 205 hectares contained within 14 land parcels, with similar land-use allocation; however essentially the same population is accommodated.

3.2.4 Change in market housing demand scenario

Ewing et al. (2007) predict that the demand for residential housing types is going to change over the next 15 years with the retirement of baby boomers. The demand for larger lot homes is going to decrease as the number of households with children decreases and the demand for smaller lots and attached homes will increase as the number of retired and single-person households' increases. The current demand for large lot homes, small lot homes and attached homes is about 50%, 25%, and 25%, respectively while the predicted demand is about 35%, 30%, and 35%, respectively (Ewing et al. 2007).

In order to accommodate this type of expected future change of community's needs, several key factors will most likely have to be modified including a new Municipal Development Plan (MDP), revisions to zoning bylaws, and altering public opinion. The creation of a new MDP and the revision of zoning bylaws are straight forward processes for the town planner and council, typically involving inter-departmental consultation, urban and infrastructure planning and limited public consultation. Changing public opinion on the other hand would require a considerable amount of time on the part of the town planner, who will have to educate the citizens on the benefits of planning to accommodate future change in the community. Unfortunately, changing community values and opinions is not typically an easy task.

In the case of the change predicted by Ewing et al. (2007), population distribution will create a change in demand for types of residential housing. Current young families in a community may not be that accepting of a future community of aging and single persons and therefore may not give any heed to planning for such a future, making the planner's job difficult. That being said, the implementation of this scenario in the model is actually quite easy; it involves: modifying the MDP values to allow for more small lots and attached homes and fewer large lot single family homes by increasing the percentages of R2 and R2X and decreasing the percentage of R1 land use; modifying the land-use bylaws to allow for higher density; and modifying the housing type market demand values to match the prediction.

The initialization of this scenario relies on the following assumptions: the MDP reflects the expected change in market demand; the planner requires more consistency with the new MDP; the density of the land-use bylaws is increased to seven units per acre; the Citizen has been educated in the changes to the MDP and land-use bylaws as well as the new building fire codes on external walls and relaxes his goal of increasing building setback; the Developer has been educated in the changes to the MDP and land use bylaw and therefore changes his density goal as well as one to one goal for market demand versus MDP.

With this scenario the Citizen's *happiness* is 6.0 to 8.0 throughout the entire simulation time. Like the business as usual scenario the Planner maintains a *happiness* of 9.0 to 10.0 throughout the simulation; the Developer's *happiness* is 9.0 to 10.0 for the first five years until the *housing demand* is met, when redesignation applications are no longer approved. During the following five years the planner continuously requests revisions, which increases the development time leaving the Developer with no choice but to not submit land-use redesignation applications causing the Developer *happiness* to fall to 2.0 to 3.0. By the end of the simulation the *development potential* is 30% greater than the *housing demand*.

Fig. 11d shows the land-use change over the ten year period based on change in market housing demand. Compared to the BAU scenario, the area over which land use has changed is significantly smaller, being approximately 176 hectares contained within 11 land parcels. The percentage of each residential land-use type follows the revised MDP regulations and *Housing type market demand* as expected: 33% R1, 31% R2 and 36% R2X, which is also visible in the land-use map.

3.2.5 Sustainable development scenario

This simulation is a combination of the "reduction in development approvals per year" scenario and the "change in market housing demand" scenario, but also includes a decrease in the dedication of wide streets from 34% wide (21 m in width) and 66% narrow (15 m in width) streets to 5% wide and 95% narrow streets, and a change of the Developers goal of *Willingness to move wetlands* to no displacement of wetlands.

Throughout this scenario, the *happiness* of all three agent types remains between 7.0 and 10.0. The Planner manages to meet the *housing demand* by year 9, the Developer has his proposed redesignation applications approved, and the Citizen has been educated on the new MDP and is pleased to that see wetlands are not being impacted.

Fig. 11e shows the land-use change over the ten year period based on the sustainable development scenario. Compared to the BAU scenario, the area over which land use has changed is significantly smaller, being approximately 198 hectares contained within 11 land parcels, and is only slightly larger than both the "change in market housing demand" and the "reduction in development approvals per year" scenarios. As expected the land-use allocation is similar to the "change in market housing demand" scenario. The change in the Developer goal to not disturb wetlands creates more intricate land-use patterns, presumably a more interesting community; however it possibly creates more complex roads and utility infrastructure.

3.3 Validation of the model

The results of the different scenarios were presented to the Planner of the Town of Strathmore and the Civil Engineer contracted by WestCreek Developments for the Strathbury development, both of whom are considered experts in their field; they were asked to provide comments and criticisms. The persons were selected based on their knowledge, their interest in this research, and their approachability. The following written comments were received from the experts on the model in general and on the results of the simulated scenarios (Engineer 2009; Planner 2009): (1) "I like the overall concept, and I think this is a great model" and "your model has some interesting elements."; (2) "You have tried to represent the data quantitatively, but I think this is a huge challenge to nail exactly."; (3) "Planning is very political and I don't know how you would accurately represent this in your model."; (4) "This type of a model would work better for a developer and their consultants."; (5) "The model did show how the various scenarios impacted the consumption of available land. This is a very positive outcome of the model."; (6) "The model predicted very similar results regardless of the scenario you used. The major exception was the ER/ MR which is more obvious based on the selection of options."; (7) "The model could use work on ER allocation by including environment data (contours, trees, water, etc.), and MR allocation by including community needs (schools, recreation needs, etc.)."; (8) "The impact of higher density (although you used only a moderately high density) did not show significant differences in single or multifamily development. Perhaps because the density used was low or because of the decision process."; (9) "The municipality really has little say on the decision to build multi-family projects; rather it is the developer who keeps a keen eye on the market and will request this type of zoning when they feel the market is there ($$). The municipality should not (and normally does not) interfere in the market, choosing one development to get an advantage over another by agreeing to multi-family for one and not another."; (10) "I did not see commercial and industrial allocation on the plans."; and (11) "I feel this tool, as it matures, can be valuable to municipalities as they try to stay ahead of demand and look towards the future."

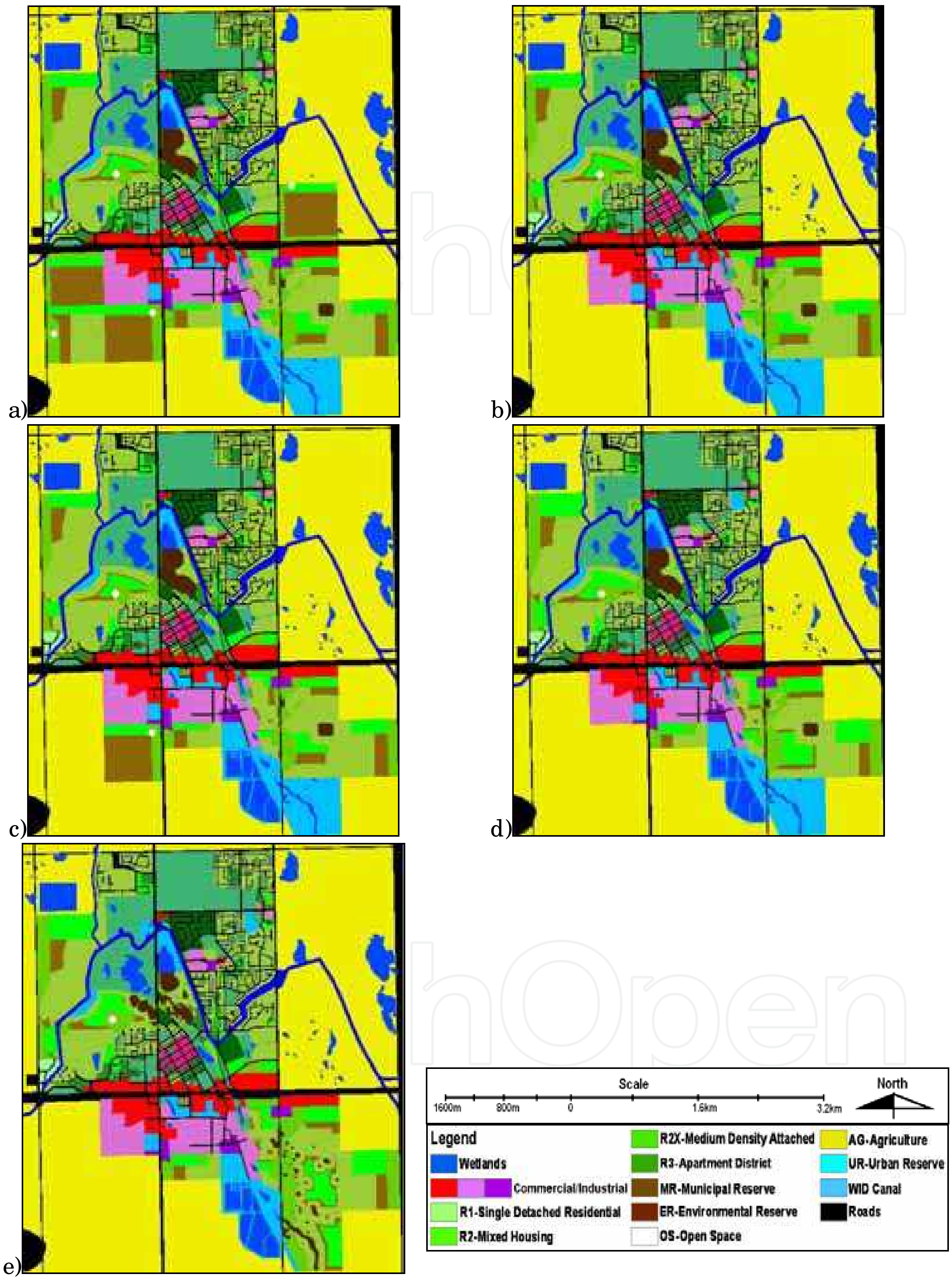

Fig. 11. Land-use maps from: a) the business as usual scenario, b) the reduction in development approvals scenario, c) the increase in density scenario, d) the change in market housing demand scenario, and e) the sustainable development scenario

The different scenarios shown above present the potential for this type of model in simulating the impact of agent goals, government regulations, design standards and market demand on land-use change, land-use patterns and pace of growth. The feedback offered by the experts provided input on the value and application of the model. It also provided interesting observations on the similarities and differences between the scenarios, as well as a potential problem in land-use allocation and the exclusion of some land uses. Constructive criticism was also given on the limitation of not including politics in the model, but also the understanding of the complexity of attempting to include politics. The comment regarding the usefulness of the model exclusively for a developer probably originates from the fact that the *land development planning* was approached from the perspective of an engineer, which is discussed in the conclusion, rather than the perspective of an urban planner and as such excludes the politics of the process. The model was also criticized for the misplacement of development control onto the Planner, as development applications approved per year, rather than onto the Developer, as development applications submitted per year.

4. Conclusion

This model is among the first attempts to contribute to the field of agent-based modelling in the Geomatics Engineering, Civil Engineering and Land-use Planning disciplines. This research has identified the fundamental parameters relevant to the *land development planning process* through a case study. The process was formalized into a simple agent-based model that accounts for social, economic, regulatory, and environmental factors. The results of the model and the comments provided by the experts show that this model has the potential to provide insight into the impact of municipal planning policies and stakeholders' goals in residential land development planning.

This research was primarily focused on the decision-making process during the *land development planning process* of the Strathbury residential land development case study. The creation of this model from an engineering aspect gave a very quantitative approach to the interview process and conceptual model development, establishing stakeholder goals as numerical figures, quantifying those factors impacting the decision-making process, and deriving formulas to mimic the decision-making process. The model allows stakeholders to test different goals and policies, providing the opportunity to quickly analyze possible future impacts before their implementation.

Since social, economic, regulatory, and environmental factors throughout Canada share several similarities, the model developed in this project has the potential to be replicated for use within another small community almost anywhere in Canada with relatively minor modifications to the parameter values. However, adapting the model to different stakeholder goals would require modifications to the computer code.

By proving the value of a simulation model having few stakeholders and a small geographical extent, the model could in the future be enhanced to include a larger number of stakeholders having more complex interactions and expanded to cover a much larger and more complex region. There are many regions in the Province of Alberta and elsewhere that would benefit from such a model.

4.1 Future improvements to the model

As mentioned by one of the experts when validating the model results, residential development cannot exist without the addition of various service sectors. The model therefore needs to be expanded to include other land development in other sectors that co-exist with residential including commercial, industrial and service.

A large number of parameters were used in this model. A sensitivity analysis can identify the parameters that are highly correlated, possibly allowing for the removal of some of them while still achieving comparable results. A sensitivity analysis can also determine the parameters that are the most influential on the system, whereby slight changes in the parameter value give rise to significant changes in the system. Based on the model results, it is believed that density and population are sensitive parameters. Since the willingness to disturb wetlands is a binary parameter, it would also be a sensitive parameter. Future work should include a sensitivity analysis of the model parameters.

The model attempts to simulate the change of behaviour of the stakeholders as the change of goals of the agents in a binary quantitative fashion. The direction of behavioural change is quite often easily derived; however the magnitude of change is not so easy. Determining the level of happiness or unhappiness, or the amount of behavioural change is quite subjective and falls into the realm of "fuzzy logic". Ligtenberg et al. (2001) state that fuzzy set theory should be explored in agent-based modelling as a way to enhance the decision making for agents. Implementing such techniques would require the expansion of interview questions to ask about past experiences, the decisions that were made and the resulting change in behaviour. The questionnaire could ask what if scenarios posed from different standpoints attempting to get a consistency in answers.

This research overlooked the "NIMBY" (Not In My Back Yard) apprehension as a behaviour of the citizen agent. In the real world, although it is not required by the developer, communities are quite often pleased when a developer requests their opinions regarding the development proposal in a voluntary pre-application meeting. They are often displeased and alarmed when they are not included only to receive the formal application and typically voicing disapproval during the public hearing. We hypothesize that "NIMBY" is a contributor to urban sprawl. Since residents of an established community have not dealt with construction and disturbance for many years, their community has most likely developed an identity and values, they may have developed a bond with their "backyard", and they have most likely established community organizations. A proposal to develop adjacent lands would create disturbance during construction, create additional traffic upon completion, and it may not fit their identity or values. Established communities will most likely oppose the proposed development and organize to defend "their backyard". This may cause developers to choose not to propose a development adjacent to an existing community having a large opposition, but rather choose land that is further away that is the "backyard" of only a few land owners driving the "urban sprawl" machine. Residents in a new community are already dealing with the construction and disturbance within their own community; their community perhaps has not developed an identity or community values, they may not have a bond or with their "backyard", and neighbourhood organizations have not been established. A proposal to develop lands adjacent to a new community creates little additional inconvenience; the residents have little bond with their adjacent lands, and they are not organized to defend their community. New communities will most likely give little consideration to the impact of new adjacent developments on their community; this lack of opposition may also be a contributor to the "urban sprawl" machine. The "NIMBY" apprehension could have been implemented as a function of the number of existing homes directly adjacent to the proposed development.

There are improvements that should be made to the model including: the shift of development control from the Planner to the Developer, acquiring actual property market value data, and updating the Municipal Development Plan (MDP). Other additions that would increase the value of the model include: (1) changing housing market value based on supply and demand; (2) adding a landowner agent to make decisions regarding the sale of their land; (3) creating a module that varies property value based on the adjacent land-use; (4) having environmental factors (topography, vegetation, and habitat) in the allocation of land use; (5) adding a utility company agent and utility infrastructure data impacting land-use change patterns; and (6) creating a dynamic Municipal Development Plan that can slowly implement the long term goals of the planning authority including major transportation corridors.

As mentioned in section 2.5.1.2, an attempt was made to allow for behavioural change of the agents. The properties of the agents would vary based on their *happiness* and how successful their *opinion* was in a decision to which it contributed. Behavioural change proved to be too difficult to implement primarily due to a lack of information on actual behavioural change from the stakeholder representative, but also due to the multiple possibilities for change. Behavioural change could come as extreme approval (greed) or disapproval (protest), concede or persevere, or remain unchanged. As an example, a happy agent whose opinion was noticed might concede a little, might remain unchanged or might persevere further. An unhappy agent whose opinion was noticed might not change, might persevere a little or might become greedy. An unhappy agent whose opinion was ignored might protest or might concede.

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6. References

Alberta Government of (2000). Guidelines for the Approval and Design of Natural and Constructed Treatment Wetlands for Water Quality Improvement. E. S. D. Municipal Program Development Branch, Environmental Service, Alberta Environment.

AltaLIS Ltd. (2007). AltaLIS Cadastral. Calgary, AltaLIS Ltd.: cadastral parcel data from Maps, Academic Data, Geographic Information Centre (MADGIC), University of Calgary

Anwar, M., C. Jeannert, et al. (2007). Conceptualization and implementation of a multi-agent model to simulate whale-watching activities in the St. Lawrence estuary in Quebec, Canada. *Environmental Modelling and Software*(22): 1775-1787.

Applied History Research Group (1997-2001). Calgary & Southern Alberta. Calgary, University of Calgary. 2009: Calgary's Growing Population chart.

Batty, M. (2001). Agent-based pedestrian modeling. *Environment and Planning B* 28(3): 321-326.

Beardsley, K., J. H. Thorne, et al. (2009). Assessing the influence of rapid urban growth and regional policies on biological resources. *Landscape and Urban Planning* 93(3-4): 172-183.

Bousquet, F., C. Le Page, et al. (2001). Multiagent simulations of hunting wild meat in a village in eastern Cameroon. *Ecological Modelling* 138(1-3): 331-346.

Bowman, T. and J. Thompson (2009). Barriers to implementation of low-impact and conservation subdivision design: Developer perceptions and resident demand. *Landscape and Urban Planning* 92(2): 96-105.

Brown and Associates Planning Group (2008). Town of Strathmore Growth Study. Strathmore, AB, Town of Strathmore.

CH2M HILL (2007). CRP Regional Servicing Study: Population Projections. Calgary, Calgary Regional Partnership,.

Citizens (2006). Letters (6) RE: Bylaw #06-17. Town of Strathmore.

City of Calgary (2008). The City Calgary Population Growth 1998-2008. Calgary, City of Calgary.

City of Calgary (2008). Guide to the Planning Process. L. U. P. Policy, City of Calgary.

City of Calgary (2009). Population Picture. Calgary, City of Calgary.

City of Calgary and Federation of Calgary Communities (2002). A Community Guide to the Planning Process. C. o. Calgary.

Crooks, A. (2006). *Exploring Cities using Agent-based Models and GIS*. Agent 2006 Conference on Social Agents: Results and Prospects, Chicago, USA.

Developer (2007). Interview with land developer stakeholder conducted by Michael Kieser: to determine his goals, behaviour and factors influencing his decision during the Outline Plan and Land Use Redesignation process of the Strathbury residential land development project.

Energy Resources Conservation Board (2007). Well sites. Calgary, ERCB: cadastral parcel data from Maps, Academic Data, Geographic Information Centre (MADGIC), University of Calgary

Engineer (2009). Letter: expert opinion validating the results of the model. Michael Kieser.

Ewing, R., K. Bartholomew, et al. (2007). *Growing Cooler: Evidence on Urban Development and Climate Change*. Chicago, Urban Land Institute.

Feuillette, S., F. Bousquet, et al. (2003). Sinuse: A multi-agent model to negotiate water demand management on a free access water table. *Environmental Modelling and Software* 18: 413-427.

Gimblett, H. R., C. A. Roberts, et al. (2002). An intelligent agent model for simulating and evaluating river trip scenarios along the Colorado River in Grand Canyon National Park. *Integrating Geographic Information Systems and Agent-Based Modeling Techniques for Simulating Social and Ecological Processes*. H. R. Gimblett. Oxford, U.K., Oxford University Press: 245-276.

Gimblett, R., T. Daniel, et al. (2001). The simulation and visualization of complex human-environment interactions. *Landscape and Urban Planning* 54(1-4): 63-79.

Government of Alberta (2000). Municipal Government Act. *M-26*. M. Affairs, Alberta Queen's Printer. RSA 2000.

Janssen, M. A., B. H. Walker, et al. (2000). An adaptive agent model for analysing co-evolution of management and policies in a complex rangeland system. *Ecological Modelling* 131(2-3): 249-268.

Ligtenberg, A., A. K. Bregt, et al. (2001). Multi-actor-based land use modelling: spatial planning using agents. *Landscape and Urban Planning* 56(1-2): 21-33.

Lim, K., P. Deadman, et al. (2002). Agent-based simulations of household decision making and land use change near Altamira, Brazil. *Integrating Geographic Information Systems and Agent-Based Modeling Techniques for Understanding Social and Ecological Processes*. H. R. Gimblett. Oxford, U.K., Oxford University Press.

Malczewski, J (1999). *GIS and multicriteria decision analysis*. Toronto, John Wiley & Sons, Inc.

Malczewski, J. and R. Moreno-Sanchez (1997). Multicriteria group decision-making model for. *Journal of Environmental Planning & Management* 40(3): 349.

Marceau, D. J (2008). What can be learned from multi-agent systems? *Monitoring, Simulation and Management of Visitor Landscapes*. R. Gimblett, University of Arizona Press: 411-424.

Mason (2010). Multi Agent Simulation Of Neighbourhood. 2010.

Minar, N., R. Burkhart, et al. (1996). The Swarm Simulation System: A Toolkit for Building Multi-agent Simulations. Santa Fe, New Mexico, Santa Fe Institute.

Monticino, M., M. Acevedo, et al. (2007). Coupled human and natural systems: A multi-agent-based approach. *Environmental Modelling & Software* 22(5): 656-663.

Moreno, N., R. Quintero, et al. (2007). "Biocomplexity of deforestation in the Caparo tropical forest reserve in Venezuela: An integrated multi-agent and cellular automata model." *Environmental Modelling & Software* 22(5): 664-673.

Musiani, M., M. Anwar, G. McDermid, M. Hebblewhite, and D.J Marceau, (2010). How humans shape wolf behavior in Banff and Kootenay national parks, Canada. *Ecological Modelling* 221: 2374-2387.

NetLogo (2010). Multi-agent Programmable Modeling Environment. 2010.

Parker, D. C., T. Berger, et al. (2002). Agent-Based Models of Land-Use/ Land-Cover Change: Report and Review of an International Workshop. W. J. McConnell. Bloomington, IN, LUCC Focus 1, Indiana University.

Planner (2007). Interview with planner stakeholder conducted by Michael Kieser: to determine his goals, behaviour and factors influencing his decision during the Outline Plan and Land Use Redesignation process of the Strathbury residential land development project.

Planner (2009). Letter: expert opinion validating the results of the model. Michael Kieser.

Repast (2010). Recursive Porous Agent Simulation Toolkit. 2010.

Statistics Canada (2007). 2006 Community Profiles - Strathmore, Alberta. 2006 Census. Ottawa, Statistics Canada: Catalogue no. 92-591-XWE. Released March 13, 2007.

Swarm (2010). Swarm: A Platform for Agent-Based Models. 2010.

Town of Strathmore (1989). Strathmore Land Use Bylaw, Town of Strathmore,. Bylaw #89-20.

Town of Strathmore (1998). Municipal Development Plan, Town of Strathmore. Bylaw #98-11.

Town of Strathmore (2007). Land use mapping. Strathmore, Town of Strathmore: Digital shapefile.

Town of Strathmore (2008). Strathmore_Asmt_Data.xls. Strathmore, Assessment Office. 2008: Assessment data for land parcels having specific LINC (Land Identification Numeric Code) numbers in the Town of Strathmore.

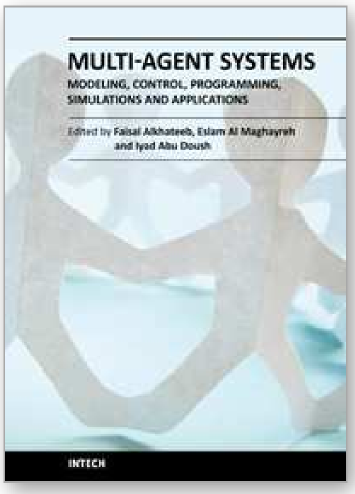
Waddell, P. (2002). UrbanSim: Modeling urban development for land use, transportation, and environmental planning. *Journal of the American Planning Association* 68(3): 297-314.

Wainwright, J. and M. Mulligan (2004). *Environmental Modeling: Finding Simplicity in Complexity*. Chichester, England, Wiley and Sons.

Wheatland County (2007). Wheatland_Asmt_Data.xls. Strathmore, Accurate Assessment Group Ltd. 2007.

White, E. M., A. T. Morzillo, et al. (2009). Past and projected rural land conversion in the US at state, regional, and national levels. *Landscape and Urban Planning* 89(1-2): 37-48.

Wooldridge, M. J. (2000). *Reasoning about Rational Agents*. Cambridge, Massachusetts, The MIT Press.



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A multi-agent system (MAS) is a system composed of multiple interacting intelligent agents. Multi-agent systems can be used to solve problems which are difficult or impossible for an individual agent or monolithic system to solve. Agent systems are open and extensible systems that allow for the deployment of autonomous and proactive software components. Multi-agent systems have been brought up and used in several application domains.

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University Campus STeP Ri
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51000 Rijeka, Croatia
Phone: +385 (51) 770 447
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Phone: +86-21-62489820
Fax: +86-21-62489821